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## **Burn Site Groundwater Interim Measures Work Plan**

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## **Burn Site Groundwater Interim Measures Work Plan**

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### **ABSTRACT**

This Work Plan identifies and outlines interim measures to address nitrate contamination in groundwater at the Burn Site, Sandia National Laboratories/New Mexico. The New Mexico Environment Department has required implementation of interim measures for nitrate-contaminated groundwater at the Burn Site. The purpose of interim measures is to prevent human or environmental exposure to nitrate-contaminated groundwater originating from the Burn Site. This Work Plan details a summary of current information about the Burn Site, interim measures activities for stabilization, and project management responsibilities to accomplish this purpose.

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## **Acronyms**

CME	Corrective Measures Evaluation
COOC	Compliance Order on Consent
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ER	environmental restoration
FY	fiscal year
GWPP	Groundwater Protection Program
HE	high explosives
IMWP	Interim Measures Work Plan
ISB	in situ bioremediation
LLNL	Lawrence Livermore National Laboratory
MCL	maximum contaminant level
MNA	monitored natural attenuation
NMED	New Mexico Environment Department
RCRA	Resource Conservation and Recovery Act
SNL/NM	Sandia National Laboratories/New Mexico
SWMU	Solid Waste Management Unit

## 1.0 INTRODUCTION

The Compliance Order on Consent (COOC), issued to the Department of Energy (DOE) and Sandia National Laboratories/New Mexico (SNL/NM) (NMED 2004) by the New Mexico Environment Department (NMED), identified the Burn Site at SNL/NM as an area with groundwater contamination requiring a corrective measures evaluation (CME). In response to the COOC, SNL/NM submitted the following two documents to the NMED in June 2004: (1) *Current Conceptual Model of Groundwater Flow and Contaminant Transport at Sandia National Laboratories Canyons Area* (SNL/NM 2004b), and (2) *Corrective Measures Evaluation Work Plan Canyons Area Groundwater* (SNL/NM 2004a). The Current Conceptual Model provides site-specific characteristics by which remedial alternatives will be evaluated. The CME Work Plan provides a description and justification of which remedial alternatives will be considered and the methods and criteria to be used in the evaluation.

On March 1, 2005, the DOE and SNL received a letter from NMED (NMED 2005), which stipulated the following guidance:

- DOE/SNL must prepare and submit an Interim Measures Work Plan (IMWP) within 90 days from the receipt of the letter (by May 30, 2005).
- NMED requires additional characterization of the nitrate-contaminated groundwater near the Burn Site. Specifically, the downgradient extent of groundwater with nitrate concentrations >10 mg/L shall be determined.
- NMED does not accept the *Corrective Measures Evaluation Work Plan Canyons Area Groundwater* (SNL/NM 2004a) because they are not satisfied with the existing characterization of nitrate-contaminated groundwater near the Burn Site.
- NMED also required the installation of one additional monitoring well “adjacent to Solid Waste Management Unit (SWMU)-94F in order to establish groundwater conditions in this petroleum-contamination source area.” This new well near SWMU-94F is not associated with interim measures and will be discussed in a separate document.

Guidance on formatting an IMWP was not provided in the COOC. Therefore, this IMWP has been formatted according to EPA guidance (EPA 1994). This IMWP was developed to present a summary of current information (Section 2.0), describe interim measures for stabilization (Section 3.0), describe project management responsibilities and the implementation schedule (Section 4.0) and discuss future submittals (Section 5.0) in order to resolve NMED’s concerns through implementation of interim measures at the Burn Site.



## 2.0 SUMMARY OF CURRENT INFORMATION

This section presents a summary of the most current information pertaining to implementation of the interim measures. This information was gathered during development of the Current Conceptual Model (SNL/NM 2004b), the CME Work Plan (SNL/NM 2004a), and other technical reports that have recently been produced as part of the CME process. Table 2-1 outlines documents that contain the information presented in Sections 2.1 through 2.5. Section 2.6 presents conclusions from information presented in Sections 2.1 through 2.5 that are applicable to the interim measures.

The CME process used a staged method to identify data gaps and gather information required to complete the CME report. Some information included in the reports listed in Table 2-1, may be superseded by data gathered during the CME process. Although these documents were developed to support the CME, most of the information and conclusions in these documents are applicable to selecting interim measures at this site. However, the conclusions presented in these documents may also be superseded by additional characterization performed during interim measures.

Table 2-1. Outline of documents produced in support of the Corrective Measures Evaluation.

Section in IMWP	Document Title	Reference or Attachment
Section 2.1	<i>Current Conceptual Model of Groundwater Flow and Contaminant Transport at Sandia National Laboratories/New Mexico Burn Site</i> (June 2004)	SNL/NM 2004b
Section 2.2	<i>Corrective Measures Evaluation Work Plan Burn Site Groundwater</i> (May 2004)	SNL/NM 2004a
Section 2.3	Remedial Alternatives Data Gaps Review for Burn Site Groundwater at Sandia National Laboratories/New Mexico, (December 2004)	Attachment A
Section 2.4	Nitrate Source Evaluation for Burn Site Groundwater at Sandia National Laboratories/New Mexico, (February 2005)	Attachment B
Section 2.5	Evaluation of Contaminant Transport for Burn Site Groundwater at Sandia National Laboratories/New Mexico, (March 2005)	Attachment C

## **2.1 Summary of the Burn Site Current Conceptual Model**

The Current Conceptual Model provides site-specific characteristics for a technically defensible remediation program (SNL/NM 2004b) and addresses the site characterization data needs of Section IV of the COOC (NMED 2004) and the Resource Conservation and Recovery Act (RCRA) Corrective Action Plan (EPA 1994). Upon review of the Current Conceptual Model, the NMED required further characterization of the Burn Site (NMED 2005). Although NMED deemed the Current Conceptual Model incomplete because the extent of the plume has not been adequately characterized, the information presented therein is pertinent to implementing the interim measures.

### **2.1.1 Contaminant Releases**

Nitrate has been identified above levels of regulatory concern in Burn Site groundwater. Diesel range organic contaminants and other organic constituents have also been detected in groundwater, but concentrations have been below levels of regulatory concern.

Nitrate in Burn Site groundwater at concentrations that exceed the Environmental Protection Agency (EPA) maximum contaminant level (MCL) of 10 mg/L may be derived either from nitrate residue from open detonation of high explosives (HE) or from concentration of nitrate during evapotranspiration of rainfall that infiltrated canyon alluvium. Nitrate from either source could accumulate in alluvial deposits in the canyon floor and be mobilized by subsequent wetting events that provide sufficient moisture to infiltrate brecciated fault zones and migrate downward to groundwater flow systems.

### **2.1.2 Contaminant Transport in Groundwater**

Groundwater in rocks underlying the Burn Site in Lurance Canyon moves as semi-confined fracture flow, eventually discharging to unconsolidated basin-fill deposits in the Albuquerque Basin to the west. Some discharge takes place to springs at the base of the Manzanita Mountains. Local recharge to this low-permeability system occurs through a series of north-trending brecciated fault zones crossing the Burn Site and the Lurance Canyon drainage. These fault zones provide a permeable conduit between the land surface and the fractured water-bearing rocks at depth.

Based on the limited streamflow information and Burn Site piezometer data, streamflows at the Burn Site sufficient to saturate channel sediments and provide a source of recharge to brecciated fault zones are sporadic and infrequent. Infiltrating water from these streamflows temporarily saturates alluvial sediments adjacent to the arroyo. Much of the water retained as bank and channel bottom storage most likely returns to the atmosphere through evapotranspiration. If infiltrating water from a flow event or sequence of events is adequate to exceed evapotranspiration losses, water moves downward through the canyon alluvium and is available to enter brecciated fault zones in underlying bedrock.

Nitrate in water from Burn Site wells is attributed to non-point sources, either from nitrate disseminated from open detonation of HE from 1967 until the early 1980s at sites within SWMU-65 or from naturally-concentrated nitrate present in rainwater that has been evaporated or transpired from alluvial deposits in Lurance Canyon. Evaluation of nitrate in sediments from nearby pristine alluvial deposits and springs discharging from fractured rocks may be useful in defining the source of nitrate in Burn Site groundwater and evaluating whether that source has been depleted (see Section 2.4). Nitrate concentrations in several wells indicate that a nitrate pulse in groundwater may have moved downgradient across the Burn Site since 1995.

Organic constituents, which to date have not been detected above regulatory concerns, are present in Burn Site groundwater. These constituents provide information about groundwater flow and contaminant migration. These organic contaminants may have moved with wastewater or jet fuel, entering bedrock at brecciated fault zones that cross the Burn Site. Trace concentrations of HE constituents in groundwater are attributed to the open detonation of HE. These constituents may have been mobilized and concentrated in infiltrating precipitation and runoff, migrating to fault zones and the groundwater.

## **2.2 Summary of the Corrective Measures Evaluation Work Plan**

The purpose of the CME Work Plan (SNL/NM 2004a) was to identify and outline a process for evaluating possible remedial alternatives that could be implemented to remediate Burn Site groundwater. This approach is pertinent to devising appropriate and protective interim measures. An initial screening of nitrate remediation technologies was performed in the CME Work Plan. This initial screening started with a list of general remediation technologies, applicable to remediation of nitrate contamination in groundwater, and screened out technologies not applicable to the Burn Site due to obvious physical constraints. The original list of technologies included:

1. Groundwater monitoring,
2. In situ bioremediation (ISB),
3. Monitored natural attenuation (MNA),
4. Monolithic confinement,
5. Permeable reactive barriers,
6. Phytoremediation, and
7. Pump-and-treat.

These technologies were described and evaluated based on meeting threshold criteria requirements for the technology to be applicable at the Burn Site. Three of the seven technologies were eliminated based on the following reasons:

1. **Monolithic confinement** was eliminated because it is an aggressive source control technology that requires constructing barriers to confine groundwater contamination, either by digging trenches or drilling closely spaced boreholes. Considering the potential size of the area with elevated nitrate concentrations, the depth to groundwater (68 to 320 ft), and the nature of the subsurface (metamorphic bedrock), constructing such a barrier would be an infeasible task. Therefore, it was determined that monolithic confinement is not an applicable technology at this site because it would not be feasible to attain cleanup goals by applying this technology.
2. **A permeable reactive barrier** constructed downgradient of the plume would need to be large enough to inhibit flow of contaminated groundwater underneath or around the barrier. Considering the potential size of the area with elevated nitrate concentrations, the depth to groundwater (68 to 320 ft), and the nature of the subsurface (metamorphic bedrock), constructing such a barrier would be an infeasible task. Therefore, it was determined that a permeable reactive barrier is not an applicable technology at this site because it would not be feasible to attain cleanup goals by applying this technology.
3. **Phytoremediation** as a stand-alone remedy (not in conjunction with pump-and-treat) is most applicable when the groundwater is within 10 ft of the surface. Implementation of this technology would be ineffective considering the depth to groundwater and the nature of the subsurface, which consists of metamorphic rock not penetrated by plant roots. Therefore, it was determined that phytoremediation is not an applicable technology at this site because it would not be feasible to attain cleanup goals by applying this technology.

These three technologies were eliminated and the initial screening resulted in a list of four technologies identified as the remedial alternatives to be evaluated for implementation at the Burn Site. The CME Work Plan outlined a staged process for evaluating these alternatives, which included paper studies; field scale studies; laboratory studies; and at a later date, it was determined that numerical modeling studies would also provide useful information for evaluating alternatives.

## 2.3 Summary of Data Gaps Review

The Data Gaps Review document is the deliverable of the paper study stage. This document included detailed definitions of remedial alternatives and a preliminary evaluation of remedial alternatives with the purpose of identifying what data gaps remain. The NMED was provided a copy of the Data Gaps Review and given an opportunity to provide feedback. Pertinent information for implementation of interim measures includes:

- **Scoping Calculations**—Scoping calculations were performed for the remedial alternative conceptual designs. One of these calculations included a rough estimate of the extent of nitrate-contaminated groundwater that was based on estimated groundwater velocity and observed contaminant breakthrough at CYN-MW1D. It was estimated that nitrate-contaminated groundwater (greater than 10 mg/L) likely extended at least 960 ft downgradient of CYN-MW1D in 2004.

- **Technology Descriptions**—Includes descriptions of the four technologies that were being evaluated, including groundwater monitoring, MNA, ISB, and pump-and-treat. These descriptions are more detailed than the technology descriptions presented in the CME Work Plan, and include information from literature concerning application of the technologies at other sites. This review demonstrated that pump-and-treat technologies have often not achieved plume remediation within a reasonable timeframe while requiring high operating costs (EPA 2001). One study suggested that pumping between 10 and 100 pore volumes of contaminated groundwater would be required to restore the aquifer (EPA 1997).
- **Remedial Alternative Conceptual Designs**—Presents conceptual designs for each of the four remedial alternatives, consisting of process diagrams, assumptions, and technical and functional requirements for each. According to the conceptual designs, site-specific constraints were significant obstacles in implementing successful pump-and-treat and ISB remedial alternatives. For instance, pump-and-treat would require extraction and treatment of between 1 and 100 gpm of contaminated groundwater from at least one extraction well for at least 25 years. During this extraction period, an appropriate and protective treatment measure would need to be implemented. The most feasible treatment would be ion exchange, which would require disposal of significant quantities of contaminated groundwater.
- **Remedy Evaluation**—Presents an evaluation of the remedial alternatives based on criteria derived from the COOC (NMED 2004) and described in the CME Work Plan. The evaluation was a preliminary evaluation intended to identify remaining data gaps. The preliminary evaluation demonstrated that the ISB and pump and treat remedial alternatives would be considerably less effective than the other two remedial alternatives. For ISB, it would not be feasible to distribute electron donor in bedrock over this large nitrate-contaminated area (approximate length of the contaminated groundwater plume is 4,000 ft) without displacing the nitrate-contaminated water. Similarly, pump-and-treat was also demonstrated to be considerably less effective than the other two alternatives based on the cost and effectiveness of pump-and-treat with the objective of restoring the aquifer.

The CME Work Plan, which was written in accordance with the COOC (NMED 2004) and RCRA guidance (EPA 1994), identified a staged approach where remedial alternatives will be screened. As part of this approach, if a remedial alternative is determined to be significantly less effective than the other remedial alternatives, then it will no longer be considered. Therefore, it was recommended that pump-and-treat and ISB no longer be considered and that data-gathering activities should focus on MNA and groundwater monitoring. The screening of remedial alternatives as updated through the Data Gaps Review is shown on Figure 2-1.

Based on this evaluation and the current level of site characterization, recommendations were also made regarding further data-gathering activities to be carried out as part of the field studies and numerical modeling stages of the CME. These activities were carried out and reports are included as attachments to this IMWP and summarized in Sections 2.4 (Summary of Nitrate Source Evaluation) and 2.5 (Summary of Nitrate Transport Evaluation).

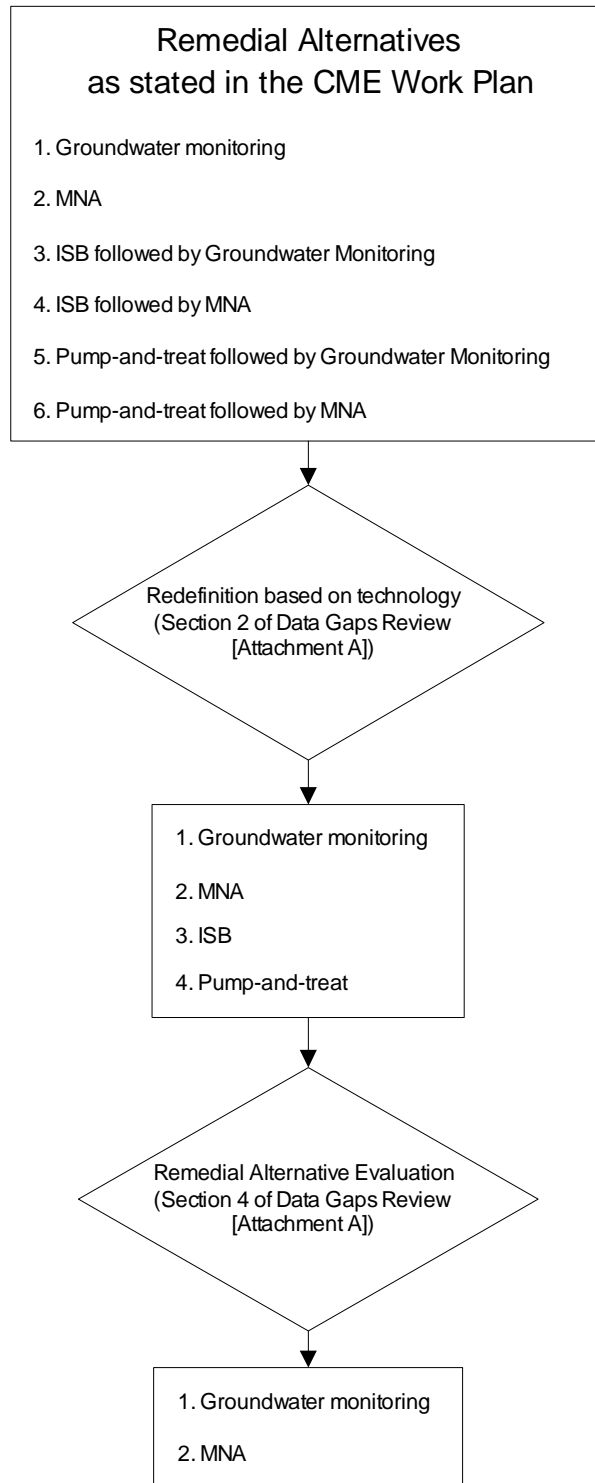


Figure 2-1. Remedial alternatives screening based on Data Gaps Review (Attachment A).

## 2.4 Summary of Nitrate Source Evaluation

One of the recommended data-gathering activities from the paper studies stage (Section 2.3) was a nitrate source evaluation to be conducted to establish background nitrate concentrations in soil and spring water and to determine if significant non-point nitrate sources are still present. Both near-surface and deep soil borings were collected and analyzed for nitrate, HE compounds, and other analytes. Water samples were also collected from nearby springs and analyzed for nitrate and water quality parameters. The results of these field activities were presented in the “Field Report Burn Site Groundwater – Nitrate Source Evaluation” (Skelly 2005).

These results were compiled, along with the Current Conceptual Model and other groundwater monitoring data, in the Source Evaluation Report (Attachment B). Evaluation of the data led to the following observations and conclusions, which are significant when considering the nature of an interim measure and the extent of characterization:

- Nitrate in alluvium and groundwater at the Burn Site is a result of both natural phenomena and historical Burn Site operations.
- Measured background nitrate concentrations in spring water and groundwater range from non-detect to less than 2.6 mg/L as nitrogen.
- Elevated nitrate concentrations in soil near the Burn Site and in a groundwater plume emanating from the Burn Site are likely the result of historical Burn Site operations, followed by leaching of nitrate into the subsurface.
- Nitrate remains in the vadose zone alluvium at the Burn Site; however, this nitrate does not represent an active source that would significantly increase nitrate concentrations in groundwater. A conservative estimate indicates that the nitrate remaining in the vadose zone is unlikely to result in groundwater contamination at concentrations higher than observed in the past.

## 2.5 Summary of Nitrate Transport Evaluation

The Evaluation of Contaminant Transport (Attachment C) consisted of a simplified cross-sectional modeling approach to simulate transport and dilution of nitrate between the current location of nitrate in Burn Site groundwater and potential human and ecological receptors. Recognizing that the cross-sectional numerical flow and transport models would not be a rigorous representation of the system, several conservative assumptions were made so that the effects of dilution would be intentionally underestimated (i.e., the simulated concentrations at potential receptor locations would be greater than the actual concentrations).

The simulation of nitrate transport resulted in the following conclusions regarding nitrate transport from the Burn Site to potential downgradient receptors:

- **Ecological receptors at springs:** The maximum concentration of nitrate in groundwater at the Burn Site observed to date is 28 mg/L. Modeling results demonstrated that this maximum concentration will be reduced to 7.8 mg/L or less before reaching the closest downgradient ecological receptor at Coyote Springs in 290 years. Given the conservative assumptions built into this numerical model, the actual observed concentration at Coyote

Springs may be less than 7.8 mg/L and may not be significantly above the NMED-approved background concentration of 4 mg/L (NMED 1997).

- **Human receptors at pumping centers:** The maximum concentration of nitrate in groundwater at the Burn Site observed to date is 28 mg/L. Modeling results demonstrated that this maximum concentration will be reduced to 0.0008 mg/L or less before reaching the closest potential human receptors at current and future production wells located in the ancestral Rio Grande lithofacies of the Albuquerque basin after more than 670 years.

## 2.6 Application of Current Information to Implementation of the Interim Measures

Information gathered during the ongoing CME process and from EPA guidance is valuable when evaluating an interim measure. An EPA memorandum (Lowrance 1991) stated that interim measures may be appropriate under any of the following conditions:

- There are releases at the facility which pose actual or imminent exposure threats to humans or ecosystems at levels of concern,
- There are releases that, if not addressed expeditiously, will result in further significant contamination of environmental media in the near to mid-term (e.g., 5-10 years), or
- The site characteristics suggest that the site may be amenable to measures designed to control or abate imminent threats or prevent or minimize the further spread of contamination.

This guidance has been considered while devising appropriate interim measures for the Burn Site, by considering the information already gathered as part of the CME. Some pertinent conclusions from the CME process include the following:

- The initial screening presented in the CME Work Plan (SNL/NM 2004a) and additional information gathered during the Data Gaps Review has resulted in a list of four remedial alternatives to be considered based on obvious physical constraints of the site.
- The preliminary evaluation presented in the Data Gaps Review (Attachment A) indicates that implementation of ISB or pump-and-treat is not appropriate for remediation of the Burn Site, either as an interim measure or final corrective measure.
- The data gathered, presented, and evaluated in the Nitrate Source Evaluation (Attachment B) indicates that there is no longer a significant source of nitrate in the vadose zone at the Burn Site.
- The numerical modeling activities performed for the Nitrate Transport Evaluation (Attachment C) indicate that contaminant migration to the closest receptor location (ecological receptors at Coyote Springs) will require over 200 years, and nitrate concentrations will be reduced to below MCLs during transport to the springs.

Considering these conclusions, an appropriate and protective interim measure was devised for Burn Site groundwater. This interim measure is described in Section 3.0.



## **3.0 INTERIM MEASURES FOR STABILIZATION**

Based on NMED's determination (NMED 2005 and summarized in Section 1 of this Work Plan), interim measures for the Burn Site groundwater are being initiated. This section presents the objective, description, and implementation of the selected interim measures.

### **3.1 Objective**

The objective of interim measures for groundwater at SNL/NM's Burn Site is to protect human health and the environment against exposure to nitrate during the CME process prior to establishing a long-term corrective action.

### **3.2 Description**

The selected interim measures include additional well installation, groundwater monitoring, and institutional controls. These interim measures will serve three purposes: 1) provide data to support the CME, 2) monitor the migration of the nitrate plume in order to provide an early warning system to trigger an action if a danger to downgradient ecological receptors (Coyote Springs) becomes apparent, and 3) protect human health and the environment by limiting exposure to contaminated groundwater.

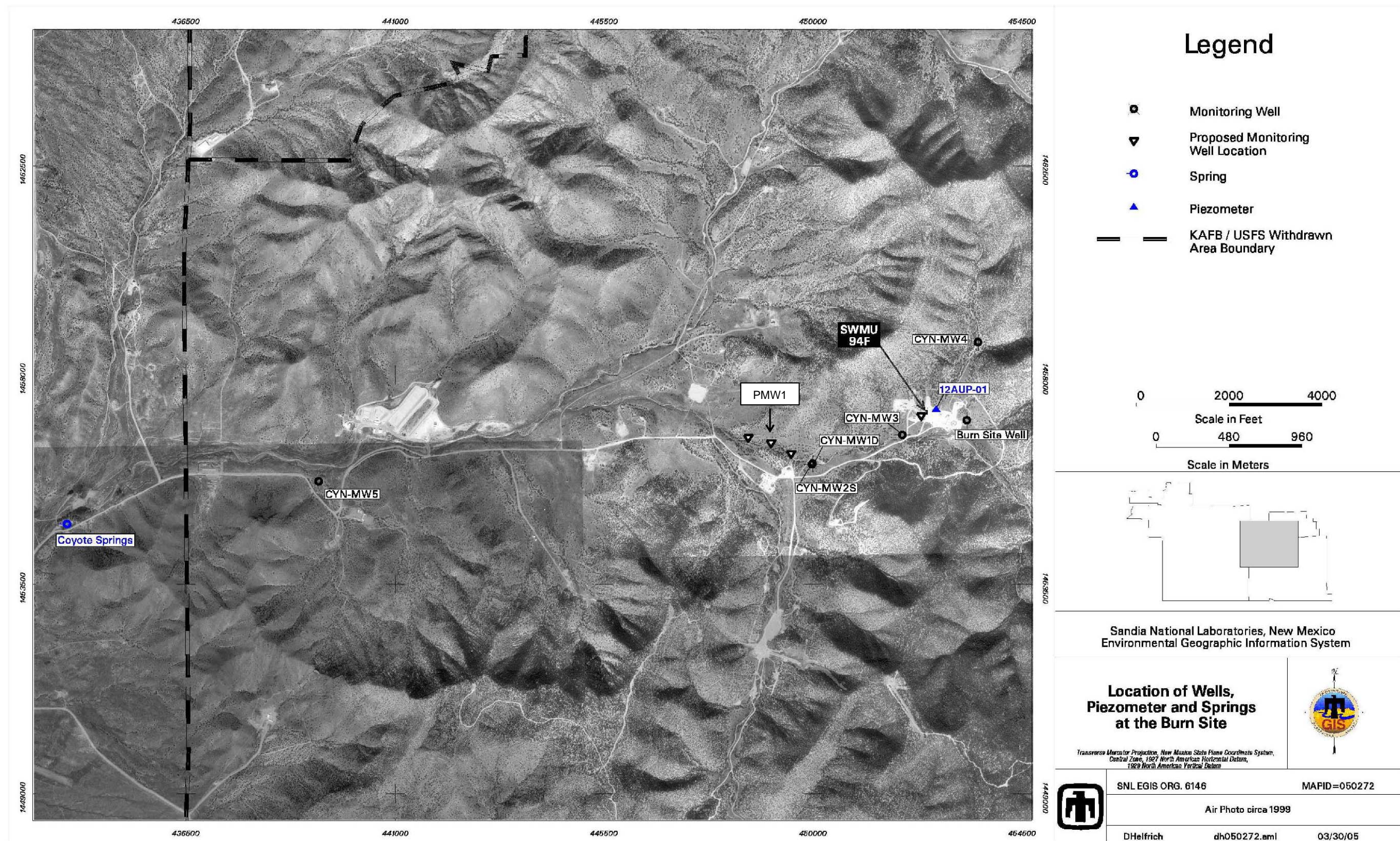
#### ***3.2.1 Additional Well Installation***

The Burn Site groundwater will be further characterized to determine the extent of nitrate contamination. Nitrate concentrations in groundwater at CYN-MW1D (Figure 3-1) have historically been as high as 28 mg/L. However, the closest downgradient monitoring well, CYN-MW5, is approximately 2 miles from CYN-MW1D. The large distance between these two wells results in considerable uncertainty in the extent of nitrate-contaminated groundwater. Additional wells will be installed between CYN-MW1D and CYN-MW5 and sampled to bound the extent of the elevated nitrate concentrations downgradient of CYN-MW1D (further described in Section 3.3). Additional characterization is needed to bound the extent of elevated nitrate concentrations and contribute to the information required to select a final corrective measure for the Burn Site groundwater.

#### ***3.2.2 Groundwater Monitoring***

The purpose of groundwater monitoring at the Burn Site area is to determine the extent of contamination and the contaminant concentrations in groundwater in accordance with the site characterization requirements listed in the COOC (NMED 2004). The existing and proposed monitoring wells at the site will be sampled to establish nitrate concentrations and trends and provide data to determine seasonal groundwater fluctuations at the site. Groundwater monitoring will provide data to support the CME. Groundwater monitoring also will track the migration of the nitrate plume in order to trigger an action if a danger to downgradient ecological receptors (Coyote Springs) becomes apparent.







### **3.2.3 Institutional Controls**

Institutional controls at the Burn Site can be broken down into engineering controls and administrative controls. Access to Burn Site groundwater will be restricted with engineering controls by locking all monitoring wells and posting warnings that identify the hazards associated with Burn Site groundwater. In addition, various administrative controls (as discussed in Section 3.3.3) are in place at SNL/NM that prevent unauthorized access to potentially contaminated groundwater. These institutional controls will protect human health and the environment by limiting exposure to contaminated groundwater.

## **3.3 Implementation**

This section describes implementation of the interim measures for Burn Site groundwater, including installation of additional wells, groundwater monitoring activities, and institutional controls. Field work associated with interim measures for the Burn Site groundwater will follow the existing Health and Safety Plan.

### **3.3.1 Additional Well Installation**

On March 28, 2005, NMED and SNL/NM personnel visited the Burn Site area to mark the potential locations of additional monitoring wells. The approximate locations of the potential monitoring wells marked during this visit are shown on Figure 3-1. Additional well installation will begin with the installation of a monitoring well (PMW1 on Figure 3-1) 1,000 ft downgradient of CYN-MW1D. PMW1 is a temporary designation; the final names for all new wells will be determined using the well naming convention set forth in the SNL/NM Administrative Operating Procedure “Well Registry and Tracking System” (SNL/NM 1997).

The distance of 1,000 ft downgradient of CYN-MW1D was chosen based on the estimated groundwater flow velocity (160 ft/yr) reported in the Current Conceptual Model (SNL/NM 2004b). Using this estimated groundwater flow velocity, the nitrate plume may have traveled over 1,000 ft downgradient of CYN-MW1D since it was first identified in 1998. Immediately after the completion of PMW1, it will be developed and sampled for nitrate. The results of this sampling will provide information to determine the appropriate location upgradient or downgradient from PMW1 for additional well(s). This well installation approach will minimize the number of wells that will need to be installed while providing the flexibility to install wells that will define the nitrate plume.

It is anticipated that two wells downgradient of CYN-MW1D will be required in order to determine the downgradient extent of the plume. However, it is possible that more than two wells may need to be installed downgradient of CYN-MW1D. As specified by NMED, the downgradient extent of the plume (within 500 ft) shall be defined as the location where the concentration of nitrate in the groundwater is less than 10 mg/L (NMED 2005).

All wells will be installed at the shallowest depth possible that will yield representative groundwater samples (NMED 2005). All wells will be installed in accordance with Section VIII (Groundwater Monitoring Wells) of the COOC and the Sandia Field Operating Procedure 94-45, “Designing and Installing Groundwater Monitoring Wells” (NMED 2004, SNL/NM 1994). Prior to well installation, a Scope of Work and a Field Implementation Plan will be prepared.

### **3.3.2 Groundwater Monitoring**

The monitoring wells at the Burn Site (CYN-MW1D, CYN-MW3, CYN-MW4, CYN-MW5, and the newly installed wells) will be sampled to establish nitrate concentrations and trends and to provide data to determine seasonal groundwater fluctuations at the site. Monitoring of the Burn Site groundwater will be conducted every two months for eight sampling events. After this initial groundwater monitoring period, the monitoring wells at the site will be sampled quarterly until the end of interim measures (implementation of the corrective measures), at which time the sampling schedule will be reevaluated.

All samples will be collected in accordance with Section IX (Groundwater) of the COOC (NMED 2004). The current site-specific sampling plan will be updated to include the new sampling locations and parameters. Per agreement with NMED, samples from the newly installed wells downgradient of CYN-MW1D will be sampled for nitrate and analyzed using EPA Method 300.0 or 353.1.

### **3.3.3 Institutional Controls**

Institutional controls at the Burn Site will protect human health and the environment by limiting exposure to contaminated groundwater. All current and future wells will be locked to prevent unauthorized access to the Burn Site groundwater. Each well will also be clearly labeled with a warning that identifies the hazards associated with the Burn Site groundwater. An example of possible monitoring well signage is shown in Figure 3-2.

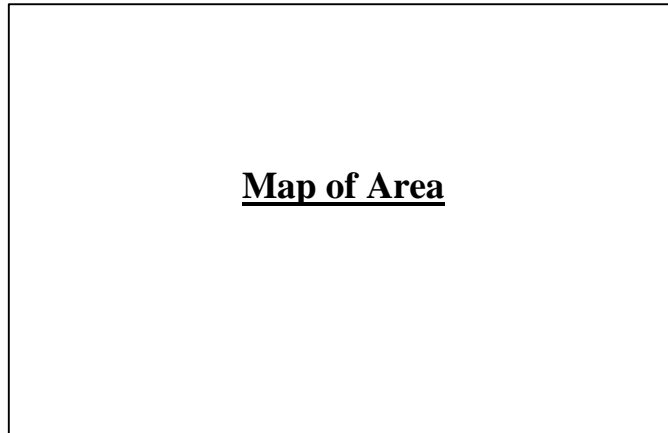
The Well Registry and Tracking System (SNL/NM 1997) must be followed prior to the installation of new wells at SNL/NM. This process requires that a well must be permitted by the Groundwater Protection Program (GWPP) prior to installation. As an administrative control interim measure, the area of potential nitrate-contaminated groundwater will be provided to the GWPP.

Prior to excavation or surface penetrations at SNL/NM, the *Excavation or Penetration Activities Procedure* (SNL/NM 2005b) must be followed. This dig permit procedure requires the identification of any subsurface activities in an environmental restoration (ER) area. The map that identifies ER areas at SNL/NM will be updated to require that appropriate personnel are contacted before installing production wells in areas of potential nitrate-contaminated groundwater.

Construction activities (including well installation) at SNL/NM must follow the National Environmental Policy Act (NEPA) process. During this process, environmental subject matter experts are consulted. These subject matter experts are aware of the potential nitrate-contaminated groundwater at the Burn Site area.

# Institutionally Controlled Area

Monitoring Well (*monitoring well name*)



Contaminated Media: Groundwater

Potential Hazards: Nitrate

## No Unauthorized Access

Point of Contact: (*List contact*)

*(Insert Contact Phone Number)*

Suggested Size: 12 inches x 12 inches

Color: Orange

Figure 3-2. Example Institutional Control Signage.

## 4.0 PROJECT MANAGEMENT

This section summarizes the project organization to implement interim measures for Burn Site groundwater. A project schedule of tasks and activities that will support the interim and corrective measures is also presented.

### 4.1 Project Organization

Figure 4-1 presents the organizational structure for the Burn Site interim measures. The primary functional entities of this project are the Regulatory Agency (NMED), DOE, Sandia Groundwater Project Leader, the Interim Measures Implementation Team, Technical Support Personnel, and the Technical Peer Review Panel.

NMED is the regulatory agency and is responsible for enforcing the requirements identified in the COOC (NMED 2004). DOE owns and operates the SNL/NM facility and Sandia Corporation is the co-operator of SNL/NM.

The Sandia Groundwater Project Leader is responsible for the overall project (i.e., scope, schedule, and budget). This position is responsible for implementing the COOC for the Burn Site and for meeting regulatory requirements, milestones, and objectives. This position also serves as an interface between the Interim Measures Implementation Team, Technical Support Personnel, and the NMED. The Sandia Groundwater Project Leader identifies and acquires technical and operational resources to complete the project scope.

The Interim Measures Implementation Team reports to the Sandia Groundwater Project Leader and works with Technical Support Personnel and the Technical Peer Review Panel. They have the overall responsibility for the execution of individual technical tasks, as well for the technical direction of the project. The Interim Measures Implementation Team is responsible for interpreting all technical data and for making decisions based on these interpretations.

Technical Support Personnel report to the Sandia Groundwater Project Leader and work with the Interim Measures Implementation Team. They are responsible for performance and oversight of all onsite field activities that are conducted in support of the Burn Site groundwater interim measures. This may include groundwater monitoring and analysis, well installation, data compilation, and report writing. Technical Support Personnel also provide site historical and process knowledge as it pertains to the Burn Site groundwater interim measures.

The Technical Peer Review Panel includes personnel from SNL/NM and CE<sup>2</sup> and may be utilized to ensure that the project is executed in the most technically rigorous and defensible manner possible. This panel, comprised of recognized experts in the field of groundwater characterization and remediation, may be used to review work plans, technical documents, and project reports. The members of the panel may also serve as technical resources for other members of the project team.

## **4.2 Project Schedule**

The project schedule has been derived through development of the interim measures requirements to identify a logical progression of tasks and activities aimed at achieving the interim measures (Figure 4-2). The basis for the schedule is development of tasks and activities, which will support the interim and corrective measures. This schedule details interim measure commitments, milestones, and NMED decision points, including deadlines for tasks to be performed for development of additional characterization knowledge, in addition to preparation of documents supporting the CME process. Documents that require NMED review and approval (i.e., this IMWP, the update to the current conceptual model, the update to the CME Work Plan, the CME report, and the CME implementation plan) have clearly defined NMED review and comment resolution periods delineated on the schedule. Dates for other subtasks are approximate and are provided for information only.

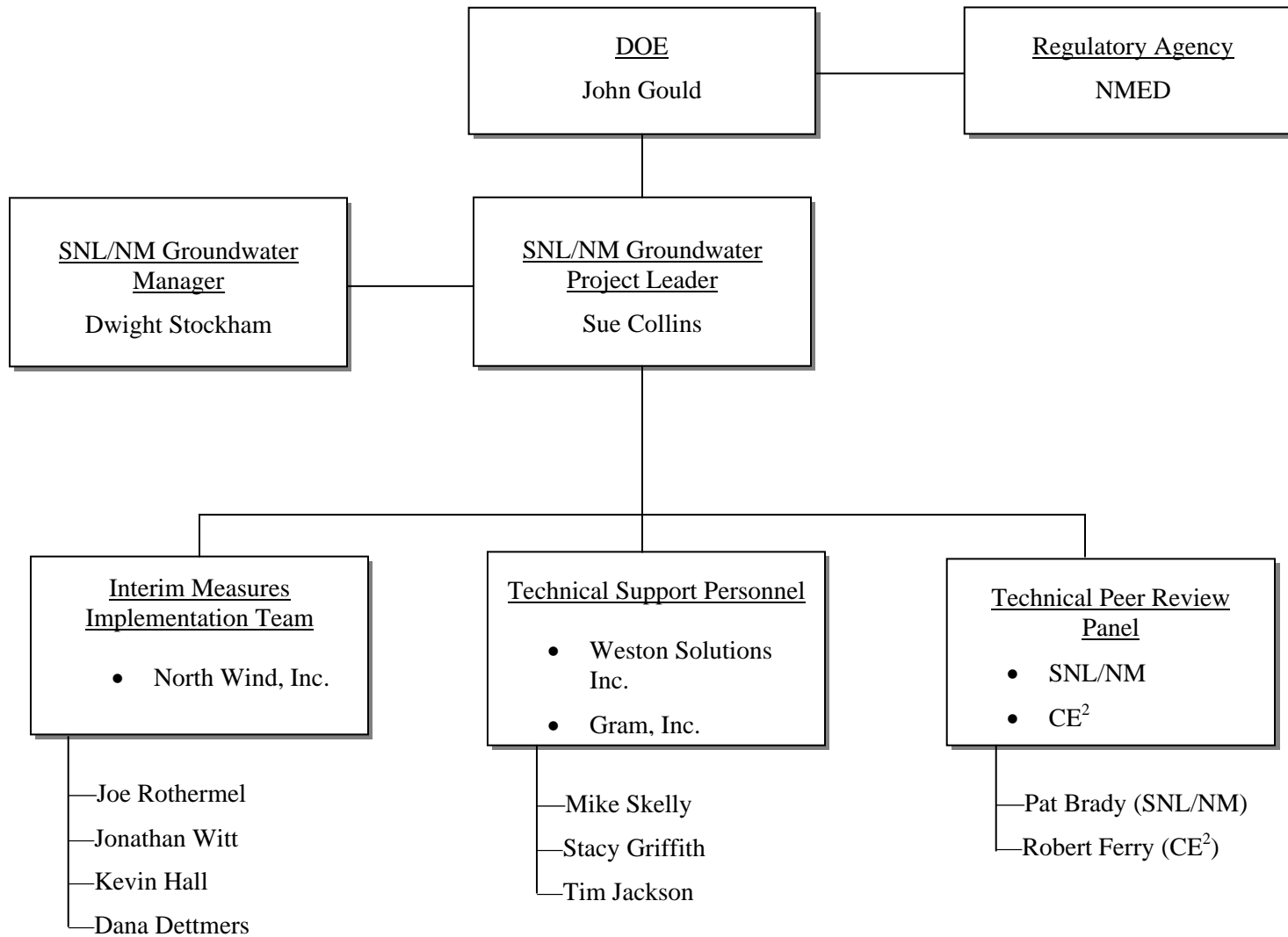


Figure 4-1. Project organizational chart for the Burn Site interim measures.



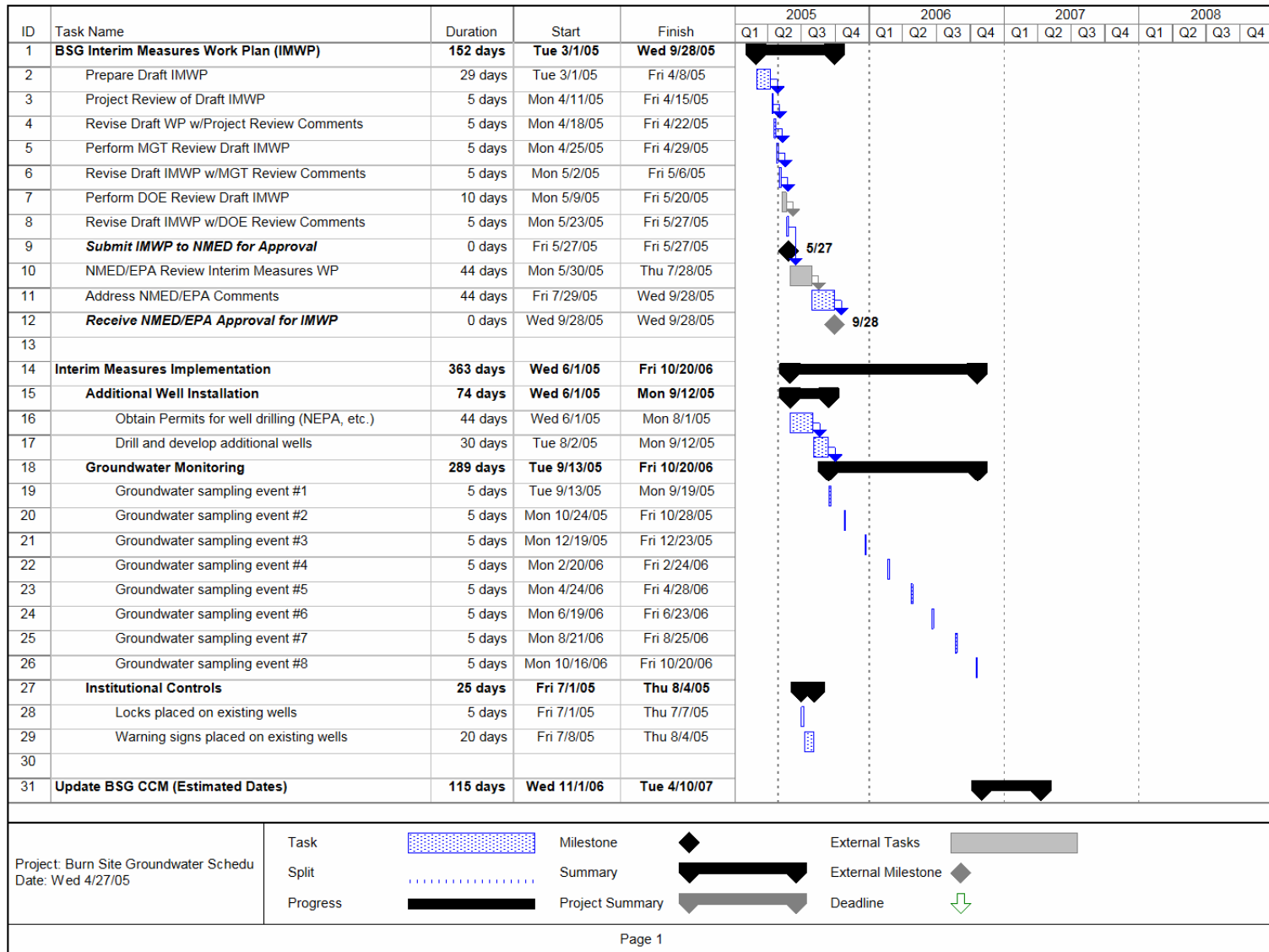


Figure 4-2. Project schedule for the Burn Site interim measures.

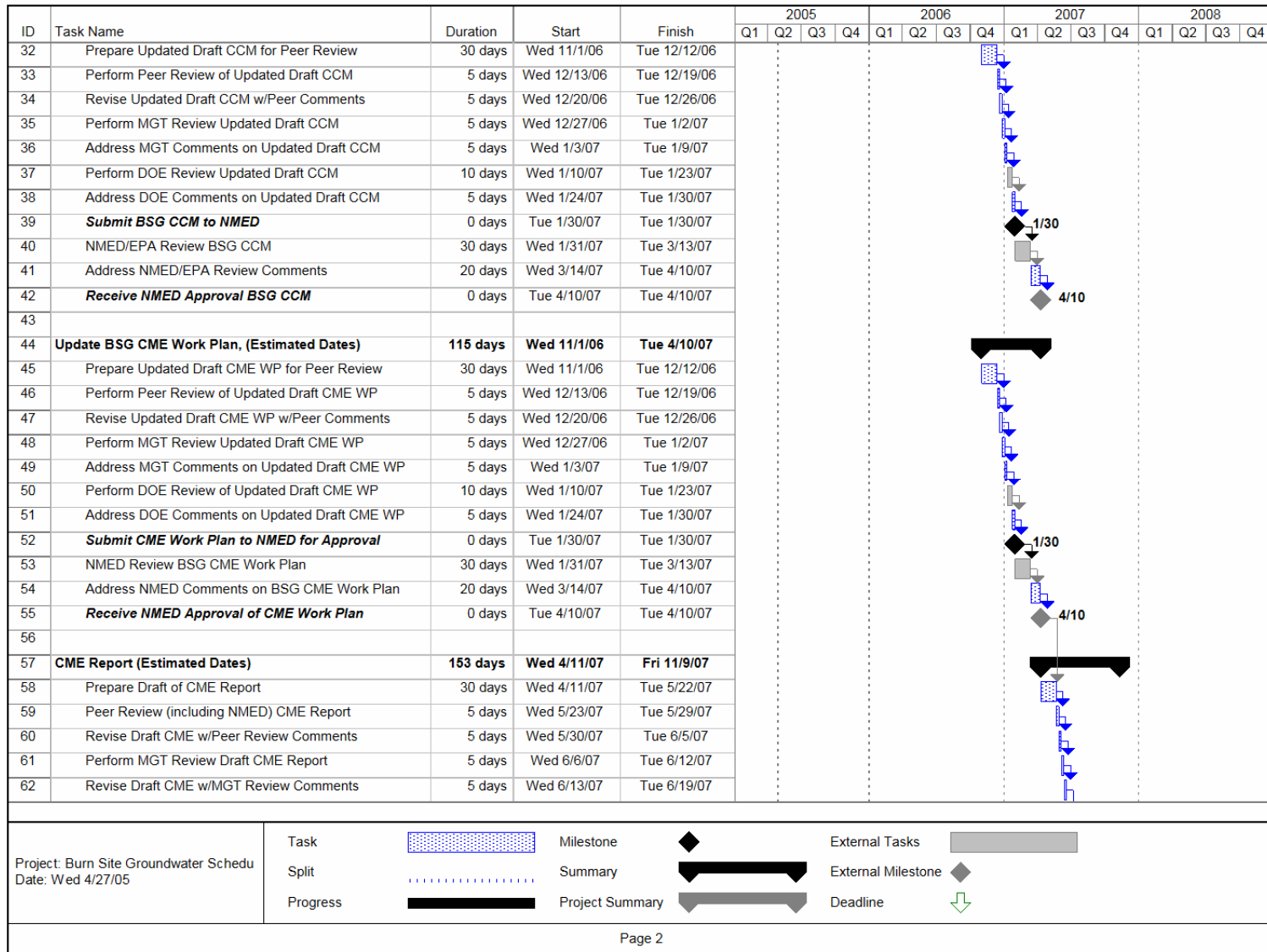


Figure 4-2. (continued).

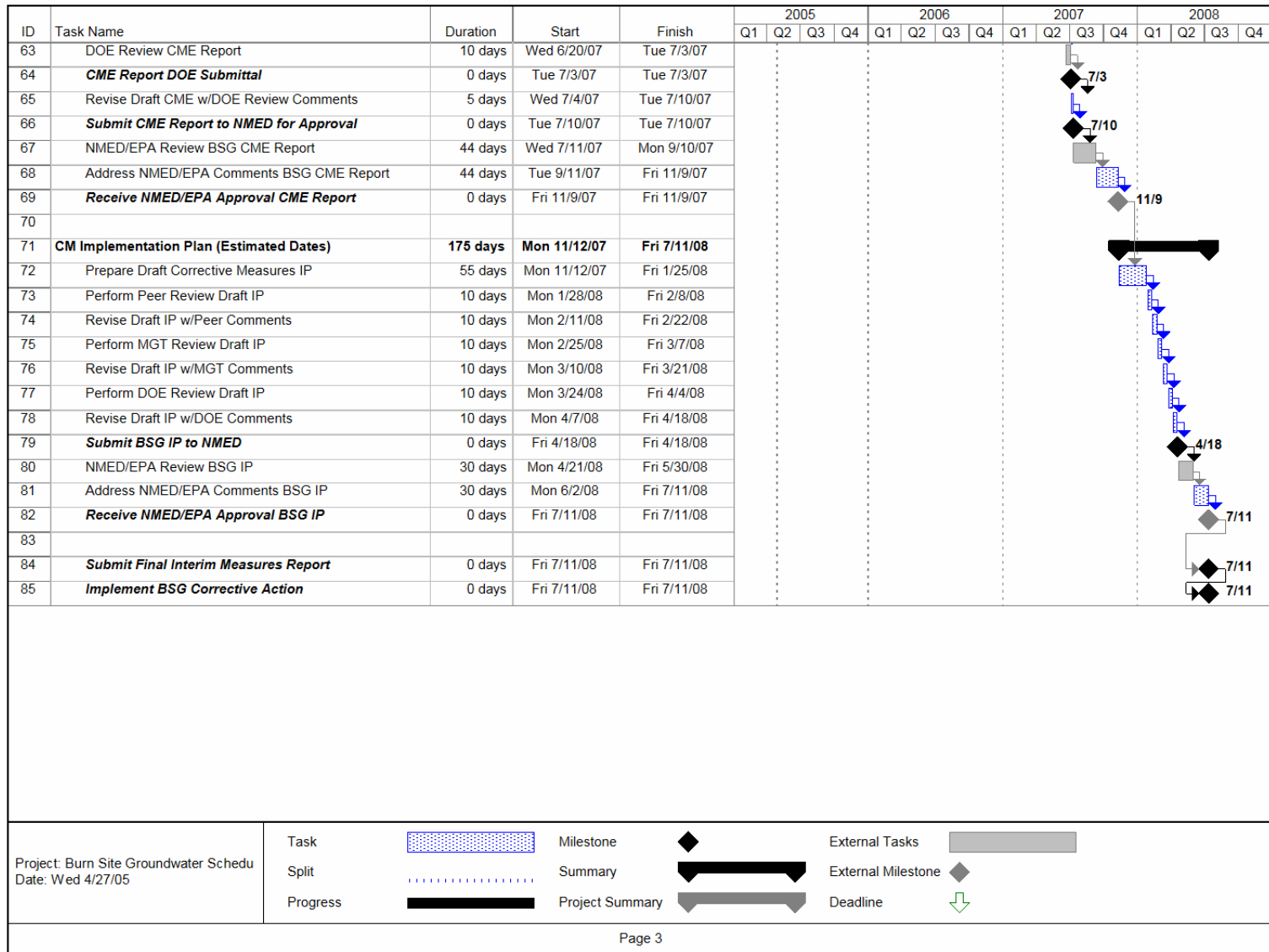


Figure 4-2. (concluded).

## **5.0 SUBMITTALS**

As shown in the project schedule (Figure 4-2), after completion of the initial bimonthly groundwater sampling events, the Current Conceptual Model of Groundwater Flow and Contaminant Transport and CME Work Plan for Burn Site Groundwater will be updated and submitted to NMED for approval. Upon approval of these documents, the CME Report will be generated and submitted to NMED for approval. After approval of the CME Report, the Corrective Measures Implementation Plan will be produced and submitted to NMED for approval. When approval is received for the Corrective Measures Implementation Plan, the corrective measure will be initiated. Interim Measures will be considered complete once the Corrective Measures Implementation Plan has been approved. The results of the interim measures will be presented in a final interim measures report according to the requirements of the COOC (NMED 2004). In addition, annual data summary reports will be submitted to NMED in order to track the effectiveness of the interim measures.

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**Attachment A**

**Remedial Alternatives Data Gaps Review  
for Burn Site Groundwater**

# **Remedial Alternatives Data Gaps Review for Burn Site Groundwater at Sandia National Laboratories/New Mexico**

**December 2004**

Prepared by  
Sandia National Laboratories  
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia is a multiprogram laboratory operated by Sandia Corporation,  
a Lockheed Martin Company, for the United States Department of Energy's  
National Nuclear Security Administration under Contract DE-AC04-94AL85000.

Approved for public release; further dissemination unlimited.



## ABSTRACT

The objective of this document is to continue the assessment of alternative technologies to support the Corrective Measures Evaluation (CME) process for remediation of Burn Site Groundwater (BSG). This Remedial Alternative Data Gap Review is an informal report that documents decisions made as a result of the assessment and recommends activities to address the data gaps and provide sufficient information to complete the CME Report. Six remedial alternatives were identified in the CME Work Plan for BSG. Section 2 of this document includes more detailed descriptions of the technologies used in the six remedial alternatives presented in the CME Work Plan for BSG. With the information presented in these more detailed descriptions, the six remedial alternatives were reduced to four. Conceptual designs for these four remedial alternatives are presented. The conceptual designs are used to perform an assessment based on the threshold and remedial alternative evaluation criteria from the Compliance Order on Consent. The six remedial alternatives, including a summary of decisions regarding each, are:

1. **Groundwater monitoring** - Groundwater monitoring will continue to be evaluated through field studies.
2. **Monitored natural attenuation (MNA)** - MNA will continue to be evaluated through field studies.
3. **In situ bioremediation (ISB) followed by groundwater monitoring** - Based on technology descriptions, remedial alternatives 3 and 4 were combined to be simply ISB. No further data gathering activities are recommended for ISB because it has been demonstrated to be significantly less effective compared to other remedial alternatives.
4. **ISB followed by MNA** - Based on technology descriptions, remedial alternatives 3 and 4 were combined to be simply ISB. No further data gathering activities are recommended for ISB because it has been demonstrated to be significantly less effective compared to other remedial alternatives.
5. **Pump and treat followed by groundwater monitoring** - Based on technology descriptions, remedial alternatives 5 and 6 were combined to be simply pump and treat. No further data gathering activities are recommended for pump and treat because it has been demonstrated to be significantly less effective compared to other remedial alternatives.
6. **Pump and treat followed by MNA** - Based on technology descriptions, remedial alternatives 5 and 6 were combined to be simply pump and treat. No further data gathering activities are recommended for pump and treat because it has been demonstrated to be significantly less effective compared to other remedial alternatives.

The outcome of this exercise is an evaluation of data gaps regarding the two remedial alternatives that are recommended for further evaluation. Field scale studies are recommended to investigate data gaps regarding the MNA and groundwater monitoring remedial alternatives. These activities should include soil and spring water sampling to characterize background nitrate concentrations and investigate the possibility of a nitrate source in the vadose zone.



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## ACRONYMS AND ABBREVIATIONS

BSG	Burn Site Groundwater
CME	Corrective Measures Evaluation
COC	contaminant of concern
COOC	Compliance Order on Consent
DOE	United States Department of Energy
DRO	diesel range organic
EPA	United States Environmental Protection Agency
ft	foot or feet
ft/bgs	feet below ground surface
ft/ft	feet per foot
ft/min	feet per minute
ft/yr	feet per year
gal	gallon(s)
gpm	gallons per minute
HE	high explosives
ISB	in-situ bioremediation
MCL	maximum contaminant level
min	minute
MNA	monitored natural attenuation
MSL	mean sea level
NMED	New Mexico Environmental Department
RCRA	Resource Conservation and Recovery Act
SNL/NM	Sandia National Laboratories/ New Mexico
T&FRs	technical and functional requirements

## 1.0 INTRODUCTION

The *Corrective Measures Evaluation Work Plan Burn Site Groundwater*, referred to in this Remedy Evaluation as the Burn Site Groundwater (BSG) Corrective Measures Evaluation (CME) Work Plan (SNL/NM 2004a), was prepared as specified in the Compliance Order on Consent (COOC) issued by the New Mexico Environment Department (NMED) (NMED 2004). The CME Work Plan for BSG outlines a process to evaluate remedial alternatives to identify a corrective measure for the Sandia National Laboratories/New Mexico (SNL/NM) BSG. As part of this process, an initial screening of remedial technologies was conducted and the results were presented in the CME Work Plan for BSG. The technologies that passed the initial screening were used to identify six remedial alternatives. These six remedial alternatives are:

1. Groundwater monitoring,
2. Monitored natural attenuation (MNA),
3. In situ bioremediation (ISB) followed by groundwater monitoring,
4. ISB followed by MNA,
5. Pump and treat followed by groundwater monitoring, and
6. Pump and treat followed by MNA.

The objective of implementing these remedial alternatives is to meet the cleanup goals, objectives, and requirements stated in the CME Work Plan for BSG, which include the following compliance goals:

- Operating all remediation systems or strategies in compliance with applicable requirements,
- Reducing contaminant of concern (COC) concentrations in groundwater to below maximum contaminant levels (MCLs), and
- Implementing institutional controls to protect human health and the environment during the remediation timeframe.

Reducing COC concentrations in groundwater to below MCLs is the main challenge for selecting the most effective and cost efficient remedial alternative for BSG; therefore, throughout this data gap review the objective to achieve for the success of each of the remedial alternatives is stated as having COC concentrations below MCLs.

Section 5.0 of the CME Work Plan for BSG, "Remedial Alternative Evaluation Plan," provides guidance on activities to be used for evaluating the six remedial alternatives (SNL/NM 2004a). The Remedial Alternative Evaluation Plan identifies data gathering activities to be carried out in three stages: (1) paper study, (2) laboratory studies, and (3) field scale studies.

### 1.1 CME Interim Documentation

As the three stages of data gathering activities are carried out, individual informal reports will be created to document the results of each stage in the evaluation process. These reports will be prepared by the CME implementation team for review by the project leader, technical peer

review panel, and technical support personnel (project organizational structure is discussed in Section 7.2 of the CME Work Plan for BSG (SNL/NM 2004a). The interim informal reports will be produced for project team internal review and discussion to define and document activities necessary to complete the BSG CME Report. The informal reports will not be officially published with Sandia document numbers and will be superseded by the data analysis and remedy selection presented in the CME report when it is published. The purpose of the informal reports includes:

- Reporting results and interpretation of results to the project leader, technical peer review panel and technical support personnel,
- Documenting decisions made during the technology data collection and analysis process for each of the three evaluation stages, and
- Providing supporting information that will eventually be included in the CME Report.

Figure 1-1 illustrates the three stage process of data gathering activities and the reports associated with each stage.

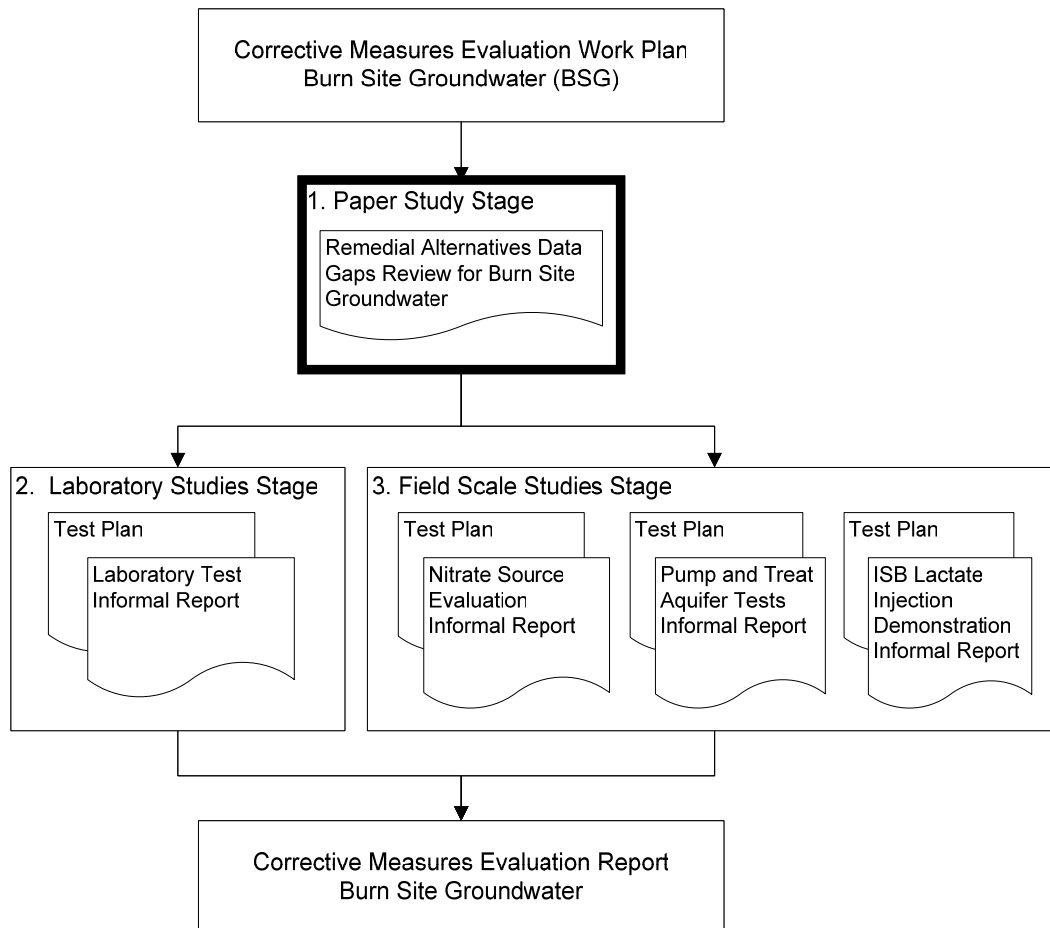


Figure 1-1. Illustration of the staged process of data gathering activities and production of subsequent reports.

## 1.2 Organization

The CME Work Plan for BSG presented objectives for a “paper study” to focus on the continuing assessment of available data and information on the alternative technologies being considered for use for BSG. The primary objectives for this assessment include presentation of conceptual designs, completion of a technology data gap review, and providing recommendations for additional activities needed to fill these data gaps to support completion of the CME Report. This document, the Alternative Technology Data Gaps Review for BSG, is organized such that each section addresses an objective of the paper study. The outcome of the process is a group of recommended data gathering activities. This data gap review document is organized into the following sections:

- **Section 1. Introduction**—This section includes a presentation of the remedial alternatives being considered, a description of the objectives of the Alternative Technology Data Gaps Review, and a summary of the *Current Conceptual Model of Groundwater Flow and Contaminant Transport at Sandia National Laboratories/New Mexico Burn Site Groundwater* referred to in this report as the Burn Site Current Conceptual Model (SNL/NM 2004b). Also, included in this section is a presentation of additional site data compiled during the paper study.
- **Section 2. Technology Descriptions**—This section provides more detail about the four technologies that passed the initial screening than the descriptions provided in the BSG CME Work Plan for BSG (SNL/NM 2004a). As additional technical details were compiled and calculated, it became apparent that two of the six remedial alternatives no longer needed to be considered for data gathering activities. Section 2 includes details on why and how the list of six remedial alternatives was reduced to four.
- **Section 3. Remedial Alternative Conceptual Designs**—This section presents the four remedial alternatives that are considered in the evaluation and provides a conceptual design, consisting of process diagrams, assumptions, and technical and functional requirements (T&FRs) for each.
- **Section 4. Remedy Evaluation**—This section presents the evaluation methods and results for each of the four remedial alternatives. The outcome of the evaluation is a list of remedial alternatives that will be considered in data gathering activities.
- **Section 5. Recommendations for Further Studies**—During the paper study, data gaps regarding individual remedial alternatives and application for BSG have been identified. This section identifies field activities that will provide the necessary information to choose a preferred remedy.

## 1.3 Site Conceptual Model Information

Subsurface properties and contaminant distribution are presented in the Burn Site Current Conceptual Model (SNL/NM 2004b). This section presents a summary of the Burn Site Current Conceptual Model, information about the BSG monitoring well network, and a presentation of information compiled during the data gaps review that are used in the evaluation of remedial alternatives.

### **1.3.1 Summary of the Burn Site Current Conceptual Model**

In Section IV.C of the COOC, the New Mexico Environmental Department (NMED) requires a CME of SNL/NM BSG contamination (NMED 2004). Remediation of COCs in groundwater at the Burn Site requires a current conceptual model of contaminant transport that will provide the basis for a technically defensible remediation program.

Nitrate has been identified as the only COC in BSG. Diesel range organic (DRO) contaminants and other organic constituents also have been detected in groundwater, but concentrations have been below levels of regulatory concern. Key elements of the current conceptual model of contaminant transport at the Burn Site are discussed below. These elements consist of contaminant releases and contaminant transport in groundwater.

#### **1.3.1.1 Contaminant Releases**

Nitrate in BSG at concentrations exceeding the MCL may be derived either from nitrate residue following open detonation of high explosives (HE) or from concentrations of nitrate from evapotranspiration of rainfall that infiltrates the canyon alluvium. Nitrate from either source could accumulate in alluvial deposits in the canyon floor and could be mobilized by subsequent wetting events that provide sufficient moisture to infiltrate brecciated fault zones and migrate downward to groundwater flow systems.

Organic constituents in groundwater have been derived from fire-suppression wastewater, spills, and HE. These constituents are not considered to be COCs because concentrations are less than EPA and state standards. However, they do provide information about the movement of groundwater in the Burn Site. DROs and other organic constituents may have migrated along brecciated fault zones to groundwater.

#### **1.3.1.2 Contaminant Transport in Groundwater**

Groundwater in rocks underlying the SNL/NM Canyons Test Area in Lurance Canyon moves as semiconfined fracture flow, eventually discharging to unconsolidated basin-fill deposits in the Albuquerque Basin to the west. Some discharge takes place to springs at the base of the Manzanita Mountains. Local recharge to this low-permeability system occurs through a series of north-trending brecciated fault zones crossing the Canyons Test Area and the Lurance Canyon drainage. These fault zones provide a permeable conduit between the land surface and the fractured water-bearing rocks at depth.

Based on the limited streamflow information and Canyons Test Area piezometer data, streamflows at the Burn Site sufficient to saturate channel sediments and to provide a source of recharge to brecciated fault zones, are sporadic and infrequent. Infiltrating water from these streamflows temporarily saturates alluvial sediments adjacent to the arroyo. Much of the water retained as bank and channel bottom storage most likely returns to the atmosphere through evapotranspiration. If infiltrating water from a flow event or sequence of events is adequate to exceed evapotranspiration losses, water moves downward through the canyon alluvium and is available to enter brecciated fault zones in underlying bedrock. Data indicate that groundwater is not present in canyon alluvial fill. However, the period of record to evaluate alluvial flow is short and may not have included periods of surface runoff.



Nitrate concentrations measured in water from Burn Site wells are attributed to non-point sources either from nitrate disseminated from open detonation of HE from 1967 until the early 1980s or from naturally concentrated nitrate present in rainwater that has been evaporated or transpired from alluvial deposits in Lurance Canyon. Evaluation of nitrate in sediments from nearby pristine alluvial deposits and springs discharging from fractured rocks may be useful in defining the source of nitrate in BSG and evaluating whether that source has been depleted. Nitrate concentrations in several wells indicate that a nitrate pulse in groundwater may have moved downgradient across the Burn Site since 1995.

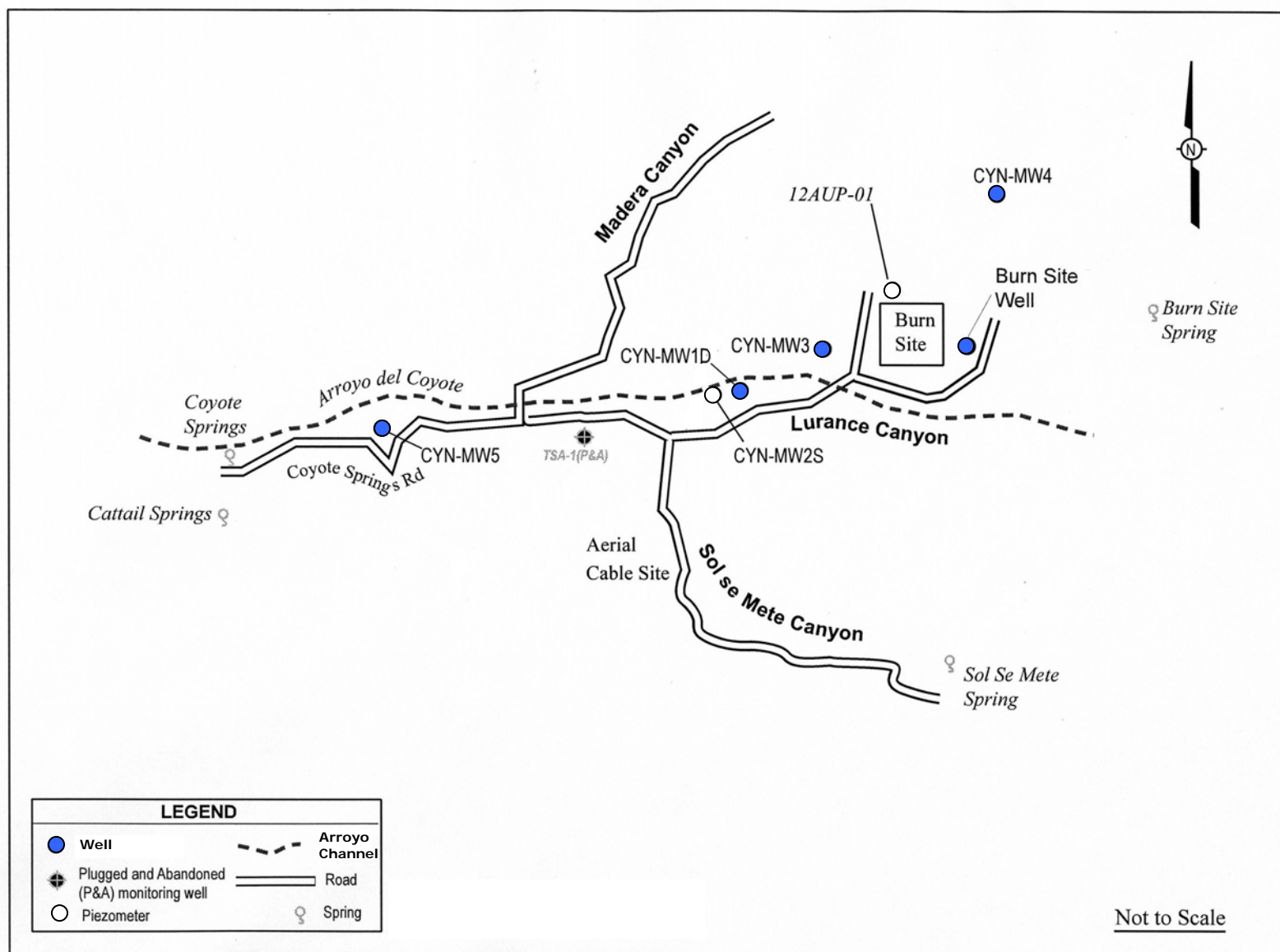
Organic constituents present in BSG are not considered to be COCs because concentrations are less than EPA and state standards. However, these constituents do provide information about groundwater flow and contaminant migration. These organic contaminants may have moved with wastewater or jet fuel, entering bedrock at buried exposures of the brecciated fault zones that cross the Burn Site. Trace concentrations of HE constituents in groundwater are attributed to the open detonation of HE. These constituents may have been mobilized and concentrated in infiltrating precipitation and runoff, migrating to fault zones and to the water table.

### **1.3.2 BSG Monitoring Well Network**

Remedial alternatives that require injection or extraction will include the cost of constructing new extraction or injection wells. BSG monitoring wells include CYN-MW1D, CYN-MW3, CYN-MW4, and the Burn Site well (SNL/NM 2004b). Well CYN-MW5 provides additional downgradient information. The locations of these wells in the vicinity of the Burn Site are shown in Figure 1-2 and summary information and completion dimensions are shown in Table 1-1. The BSG monitoring well network includes wells determined to be located at potential sources for groundwater contamination (performance wells), including CYN-MW3 and CYN-MW1D. Additionally, the network includes a cross-gradient well (CYN-MW4) that monitors potential contaminant migration through the north-trending brecciated fault zone. The network also includes a downgradient well (sentry well), CYN-MW5. No upgradient background well is located east of the Burn Site. However, several springs located more than three miles west of the Burn Site beyond the mouth of Lurance Canyon, are points of discharge from the regional flow system; the potential water-chemistry effect of the Burn Site on flow from these springs will be minimal. These springs should provide adequate background information about regional nitrate concentrations.

### **1.3.3 Information Compiled during the Data Gap Review**

Two parameters necessary for scoping calculations performed as a part of this data gap review were not directly estimated in the Burn Site Current Conceptual Model. Therefore, these parameters were estimated and the results are presented here and in Appendix A. The two parameters are the predicted specific capacity of a hypothetical well at the Burn Site and an estimation of the size of the contaminant plume. These estimations are not intended to be used in a remedial alternative design; rather, they have been used to demonstrate the feasibility of implementing the remedial alternatives.



From SNL/NM 2003.

Figure 1-2. Location of wells, piezometers, and springs in the Canyons Test Area.

Table 1-1. BSG monitoring wells.

<b>Well Name (Type)</b>	<b>Date Installed</b>	<b>Top of Screen (ft bgs)</b>	<b>Bottom of Screen (ft bgs)</b>	<b>Depth to Water<sup>a</sup> (ft bgs)/Elevation (ft above msl)</b>
<b>Cross-gradient Wells</b>				
CYN-MW4 (monitoring well)	June 1999	260	280	208.27 / 6,244.54
<b>Performance Wells (near contaminant sources)</b>				
Burn Site Well (non-potable production well)	February 1986	231	341	No Data from 2002
CYN-MW1D (monitoring well)	December 1997	372	382	320.66 / 5,916.26
CYN-MW3 (monitoring well)	June 1999	120	130	112.73 / 6,198.18
<b>Sentry Wells (downgradient)</b>				
CYN-MW5 (monitoring well)	August 2001	160	170	106.30 / 5,875.26

a. Measured in August 2002 (SNL/NM 2002).

ft bgs = feet below ground surface

msl = mean sea level

Remedial alternatives involving pumping or injection require installation of new wells. The achievable extraction or injection rates Burn Site wells were estimated using data collected during recent sampling events. Water-level drawdown measured during well purging was used to provide a rough order of magnitude estimate of the specific capacity that might be expected for a new well. The results, shown in Appendix A, suggest that the specific capacity of a new well would be expected to range from 0.03 to 33 gpm/ft of drawdown. This estimate of well specific capacities does not come from controlled pumping tests; therefore, it is only used in scoping calculations for the pump and treat technology and should not be used for design purposes.

The dimensions of the nitrate groundwater plume are pertinent when evaluating remedial alternatives and considering the utility of further evaluation of these remedial alternatives during the CME. The length of the plume in the direction of groundwater flow is estimated to be at least 4,000 ft. This is estimated based on the following conservative assumptions:

- Nitrate is consistently detected in CYN-MW1D and CYN-MW3. The monitoring well CYN-MW1D is approximately 2,000 ft downgradient of CYN-MW3.
- Nitrate was detected in CYN-MW1D in 1998 when it was first sampled. Therefore, considering the minimum transport velocity estimate of 160 ft/yr (SNL/NM 2004b), the nitrate-contaminated water would be expected to extend at least 960 ft beyond CYN-MW1D by 2004.
- Nitrate concentrations have declined to concentrations below the MCL in the Burn Site well in 2001. Therefore, it might be expected that the vicinity of the Burn Site well represents the upgradient extent of the plume. The Burn Site well is approximately 1,500 ft upgradient of CYN-MW3.

The sum of these distances is 4,460 ft. However, the plume may have moved beyond the Burn Site well since 2001, and 4,000 ft is a conservative total length estimate. Some indication of the vertical extent of the plume is demonstrated by the detection of nitrate 50 ft below the water table in CYN-MW1D and closer to the water table in CYN-MW3. A more complete characterization of the vertical extent is impractical given the physical constraints of the fractured rock system, and considering that the length of the plume already demonstrates that it is very large relative to practical application of some remedial alternatives.

## **2.0 TECHNOLOGY DESCRIPTIONS**

Four technologies are applied in various combinations to create the six remedial alternatives presented in the CME Work Plan for BSG (SNL/NM 2004a). These technologies include:

- Groundwater monitoring,
- MNA,
- ISB, and
- Pump and treat.

The purpose of this section is to provide details about each technology, including considerations for evaluation and implementation at BSG. This information is compiled from a review of the current literature, professional experience, and from calculations performed as part of the data gaps review (Appendices B and C).

This analysis has resulted in redefining the remedial alternatives that are evaluated. As additional technical details were compiled and calculated, it became apparent that several of the six remedial alternatives no longer needed to be considered. Therefore, this section includes details on how and why the six alternatives presented in the CME Work Plan for BSG were reduced to the four alternatives considered in this document. A revised list of remedial alternatives is presented in Section 2.5.

### **2.1 *Technical Description of Groundwater Monitoring***

Implementation of groundwater monitoring technology consists of monitoring COCs. This technical approach is applied as a stand-alone remedial alternative and may be applied as part of other remedial alternatives.

#### **2.1.1 Considerations for Evaluation of Groundwater Monitoring**

Advantages of groundwater monitoring, relative to more active remediation technologies, include a small secondary waste stream and no requirements for the construction of treatment facilities. The existing monitoring well network would need to be maintained.

#### **2.1.2 Implementation of Groundwater Monitoring at BSG**

The conceptual design for implementing a groundwater monitoring technology includes a description of the monitoring well network and a preliminary design of the monitoring strategy. It is assumed that implementation of groundwater monitoring as a long-term corrective action would include two operational phases: performance operations and long-term operations (Table 2-1). Performance operations include annual sampling and reporting during a period when performance is monitored and a long-term strategy is devised. Long-term operations include annual monitoring of these wells with an annual data review and a reporting requirement every 5 years. Remedy implementation would continue until compliance objectives are met.

Table 2-1. Groundwater monitoring operational phases.

Operational Phase	Monitoring Frequency	Reporting Frequency	Timeframe
Performance Operations	Annual	Annual	TBD
Long-term Operations	Annual	5 Years	TBD

TBD = to be determined.

## 2.2 Technical Description of Monitored Natural Attenuation

MNA is the reliance on natural attenuation processes to achieve site-specific remedial objectives within a reasonable timeframe (DOE 1999). For the BSG, MNA is applied as a stand-alone remedial alternative and is also applied as part of other remedial alternatives. Sections 2.2.1 and 2.2.2 describe considerations for evaluation and implementation of MNA.

### 2.2.1 Considerations for Evaluation of MNA

Guidance for determining favorable conditions for MNA comes from:

- “Use of MNA at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites” (EPA 1999), and
- *Decision-Making Framework Guide for the Evaluation and Selection of Monitored Natural Attenuation Remedies at Department of Energy Sites* (DOE 1999).

Source control technologies are to be used to control an active source term, which has been defined as a source inventory of contaminant that is being released to the groundwater where the rate of contaminant release is greater than attenuation rates such that the inventory of mobile contaminants is increasing over time (DOE 1999). One important conclusion from the Burn Site Current Conceptual Model is there is no point source of nitrate; therefore, source control measures will not be an applicable component of a remedy for BSG.

Figure 2-1 is a decision framework for implementing MNA (DOE 1999). The first tier of decision-making includes two options: (1) the contamination currently does not pose an unacceptable risk, there is no active source term, and plume contours are static or retreating or (2) data suggest attenuation mechanisms are operable or exist. Given these criteria and site-specific information, MNA can be a viable remedial alternative or portion of a remedial alternative for BSG and any remedy involving MNA will be compared to the second and third tier criteria as the CME progresses. The applicability of MNA to reduce COC concentrations to below MCLs in a reasonable timeframe is evaluated as part of the ongoing remedial alternative evaluation process.

### 2.2.2 Implementation of MNA at BSG

Implementation of MNA as a stand-alone remedial alternative would occur in two phases: 1) the performance operations phase and 2) the long-term operations phase (Table 2-2). The timeframe of these phases would be determined based demonstration that MNA will reduce COC concentrations to below MCLs. Prior to MNA implementation, characterization activities would be performed to determine whether intrinsic contaminant attenuation is taking place in the subsurface and to determine an appropriate monitoring strategy.

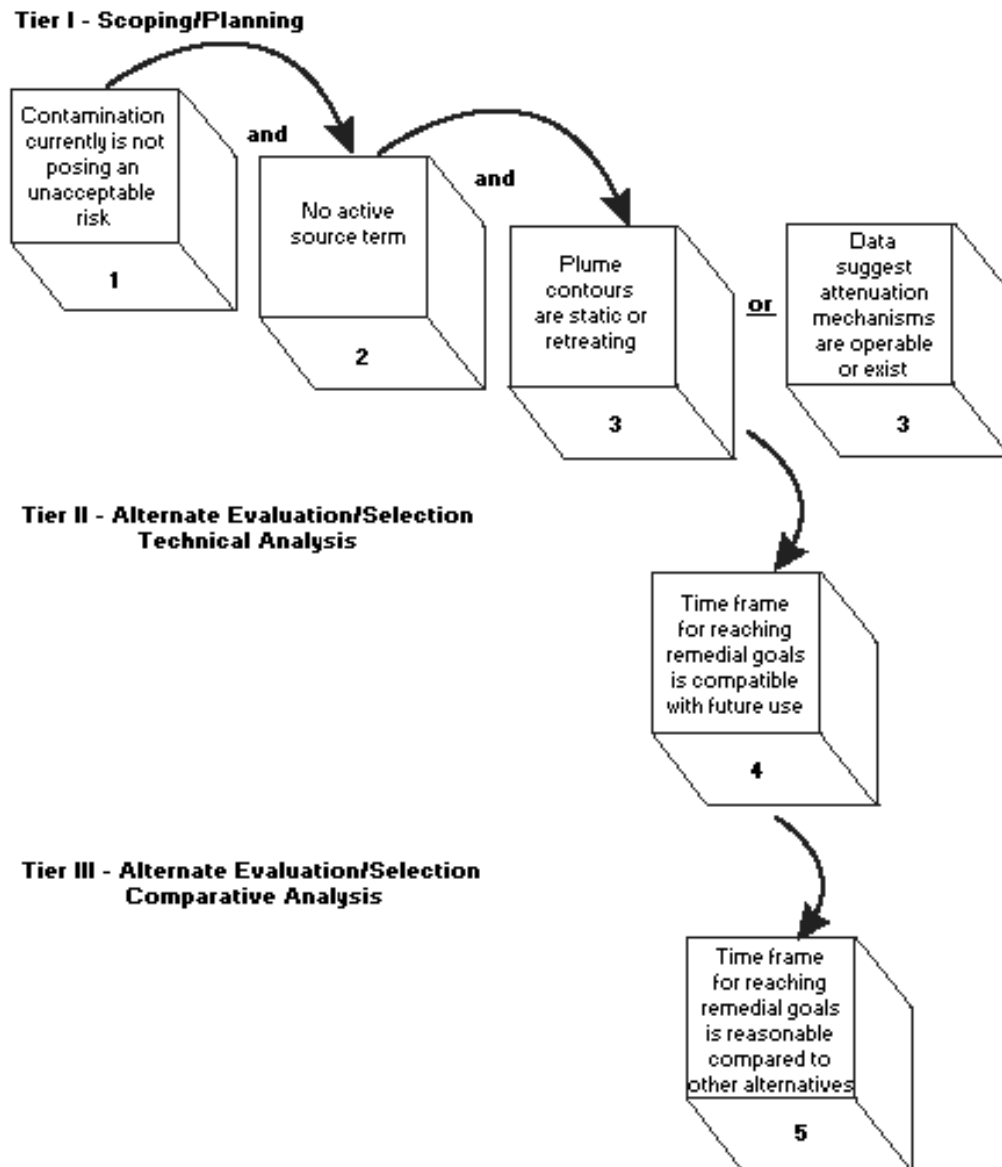


Figure 2-1. Decision framework for evaluating MNA (from DOE 1999).

Table 2-2. MNA operational phases.

Operational Phase	Monitoring Frequency	Reporting Frequency	Timeframe
Performance Operations	Annual	Annual	TBD
Long-Term Operations	Annual	5 Years	TBD

TBD = to be determined

Monitoring is a key component of any MNA remedial alternative. Monitoring would begin during performance operations with the purpose of confirming natural attenuation processes and would continue through long-term operations to track the progress of MNA. The monitoring strategy would include clearly defined sampling frequency utilizing the current monitoring well network. A preliminary sampling frequency is summarized in Table 2-2. Analytes would include COCs and possibly other parameters to assess MNA performance.

### 2.2.3 Natural Attenuation Mechanisms

Natural attenuation mechanisms of nitrate may include degradation and dispersion. Dispersion is the most likely attenuation mechanism for nitrate although degradation of nitrate may also occur. Denitrification is a process through which microorganisms facilitate the reduction of nitrate to the innocuous nitrogen gas. In low-oxygen environments, microorganisms carry out respiration through reactions utilizing chemicals other than oxygen as terminal electron acceptors. These electron acceptors typically include sulfate, nitrate, oxidized metals, and carbon dioxide. Of these nitrate is one of the more thermodynamically favorable electron acceptors (Figure 2-2).

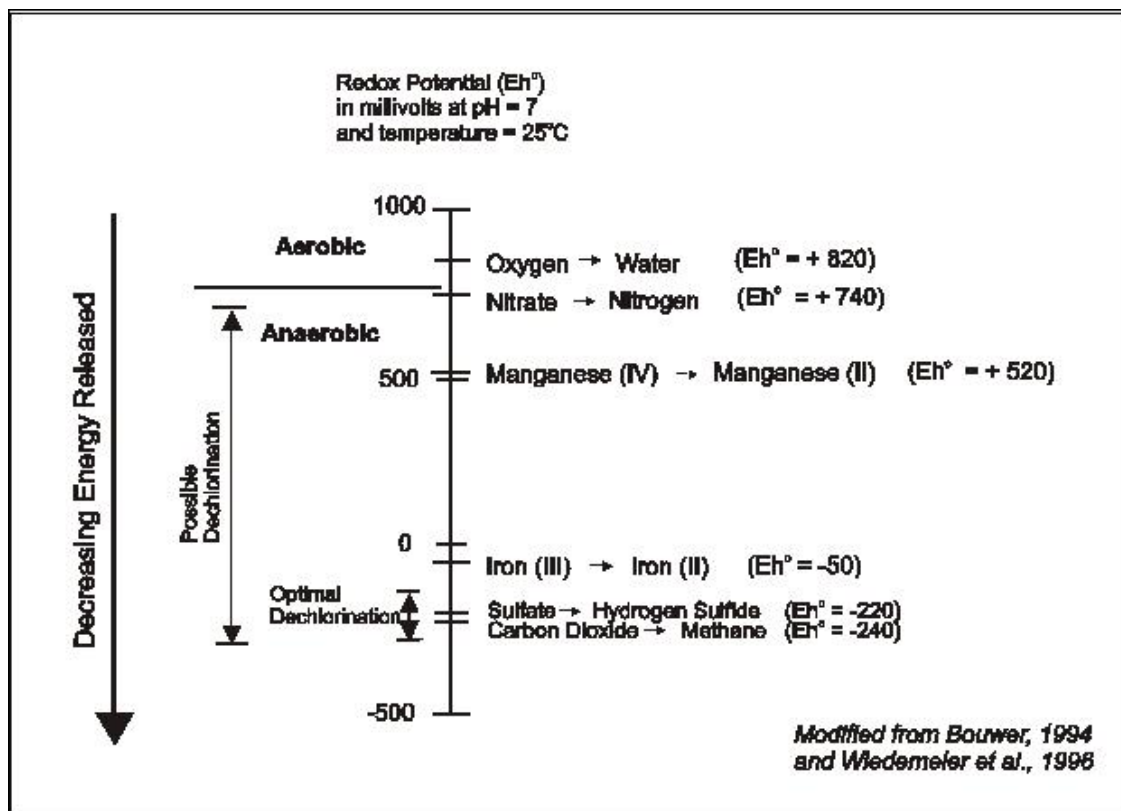


Figure 2-2. Energy available from typical microbially mediated redox reactions, and their relationship to denitrification.

### 2.3 Technical Description of In Situ Bioremediation

ISB is implemented by adding degradable organic carbon and/or nutrients to the aquifer. Indigenous microorganisms then increase in population and utilize available electron acceptors as they degrade organic carbon. The free energy yielded by redox reactions varies substantially depending upon the electron acceptor, as shown in Figure 2-2. During respiration, microorganisms preferentially utilize the electron acceptors yielding the greatest free energy. Figure 2-2 shows that the order of preference for the most common inorganic electron acceptors is oxygen, nitrate, manganese (IV), iron (III), sulfate, and carbon dioxide. Therefore, the dominant microbial community in a groundwater system is largely dependent upon the distribution of electron acceptors. Where oxygen is plentiful, aerobic bacteria will predominate; where oxygen is depleted but nitrate is plentiful, nitrate-reducing bacteria will predominate; and so on.



ISB is applicable to induce denitrification in BSG. It has been proposed for two remedial alternatives, (1) ISB followed by MNA, and (2) ISB followed by groundwater monitoring. During the data gaps review, it became evident that it would not be necessary to implement separate MNA or groundwater monitoring components following implementation of ISB, because implementation of ISB would likely be sufficient to reduce COC concentrations to below MCLs and would include confirmatory monitoring. Therefore, the two ISB remedial alternatives: ISB followed by groundwater monitoring and ISB followed by MNA, have been redefined as a single remedial alternative that is referred to as ISB. Monitoring would be a component of ISB and would include confirmatory monitoring following injections of electron donor.

### **2.3.1 Implementation of ISB Technology at BSG**

ISB technology would be implemented by injecting an aqueous phase electron donor (i.e., sodium lactate) into an injection well or several injection wells placed within the area of highest contamination. If sufficient electron donor is delivered to the volume of contaminated groundwater and reducing conditions are achieved, then nitrate will be reduced to nitrogen gas. Therefore, it may only be necessary to inject electron donor once or twice to degrade all of the COC.

### **2.3.2 Considerations for Evaluation of ISB**

Due to several characteristics of the Burn Site and of the COC, successful implementation of ISB technology would not be practical. These characteristics include:

- Nitrate is not a sorbing contaminant. A significant volume of water would need to be injected into the aquifer to distribute the electron donor. This injection would at least partially displace nitrate-contaminated water, and the contact between the amendments and the contaminated water would be limited to some mixing during injections.
- The plume is at least 4,000 ft long (see Section 1.3.3). Considering the apparent length of the contaminant distribution, multiple injection wells would be required and distribution of electron donor over such a large area would not be practical.
- Contaminated groundwater is in rocks underlying the Burn Site and moves as semi-confined fracture flow complicated by the presence of north trending faults. This system will further complicate distribution of electron donor and well drilling.

## **2.4 *Technical Description of Pump and Treat***

Pump and treat is a term used to describe the pumping of contaminated groundwater to the surface where it can be treated. The system would consist of at least one extraction well used to extract contaminated groundwater, an ex situ treatment system, and a disposal method for the treated water. Disposal of treated water could occur onsite through injection to the aquifer or by some other method.

A pump and treat technology is applied in two of the proposed remedial alternatives: Pump and treat followed by groundwater monitoring, and pump and treat followed by MNA. During the data gaps review, it became evident that it would not be necessary to implement separate MNA or groundwater monitoring components following implementation of pump and treat, because the contaminant plume will be contained by pump and treat, and the pump and treat remedy would include confirmatory monitoring. Therefore, the two remedial alternatives involving pump and treat have been redefined as a single remedial alternative that will be referred to as pump and treat.

#### **2.4.1 Considerations for Evaluation of Pump and Treat**

Pump and treat is one of the most widely used groundwater restoration technologies, as it is implemented at about three-quarters of the Superfund sites with contaminated groundwater and at most sites where cleanup is conducted under the Resource Conservation and Recovery Act (RCRA) and state laws (EPA 1996). It is a well-developed technology that is applicable for nitrate. Pump and treat is appropriate for both contaminant reduction and containment of a contaminant plume.

A review of Environmental Protection Agency (EPA) literature on pump and treat reveals that this technology has had several significant disadvantages in meeting clean-up goals at other sites. Favorable conditions for accomplishing cleanup using pump and treat include contaminants that do not sorb and a homogeneous permeable aquifer (EPA 1997). Nitrate is not expected to sorb within the fractured-rock aquifer at the Burn Site. However, the aquifer is heterogeneous and groundwater flow is affected by the presence of faults. Slow contaminant transport and interphase transfer has caused many pump and treat systems to continue to operate for decades (EPA 1997). An evaluation of 32 selected pump and treat systems showed they require on average \$4.9 million in capital costs and \$730,000 in annual operating costs. Despite this, only two of the sites surveyed have been cleaned up (EPA 2001).

#### **2.4.2 Considerations for Implementing Pump and Treat for BSG**

Two approaches to pump and treat described in EPA guidance (EPA 1997) were initially considered applicable for BSG. These two approaches were:

- Removing a sufficient number of pore volumes from within the contaminated aquifer volume to restore the aquifer, and
- Capturing the contaminant plume as it is transported across a downgradient transect or plane.

The first approach involves removing groundwater from the contaminated zone and essentially flushing that zone with uncontaminated groundwater from outside to remove dissolved contaminants and contaminants that are sorbed to aquifer materials or located within pore water that is not readily accessible. Extraction well(s) may be placed strategically to both contain the plume and remove contaminants. This is accomplished by removing multiple pore volumes of water. It has been suggested that it may be necessary to pump between 10 and 100 pore volumes to remove contaminants from an aquifer (EPA 1997). At the Burn Site, poor hydraulic communication exists between wells and the hydraulic gradient estimates range from 0.07 to 0.14 ft/ft. Considering these properties extracting and treating the contaminated groundwater from within the contaminant plume is less feasible than the second approach.

The second approach involves capturing the contaminant plume by maintaining a sufficient capture zone downgradient of the contamination until the nitrate-contaminated water has been captured. In order to achieve an appropriate capture zone a new pumping well or wells would be required downgradient of the contamination. Further site characterization would be needed prior to implementation to determine a proper location and completion for pumping wells and determine achievable pumping rates and capture zones.

### **2.4.3 Scoping Pumping Requirements at BSG**

Approximate order-of-magnitude scoping calculations, using site-specific information, have been performed to develop a conceptual design for the pump and treat remedial alternative, which is presented in Section 3. These calculations, presented in Appendix B, were performed to provide a basis for comparing operational timeframes and the extent of operations. From these calculations, one or more new extraction wells would be constructed. Water extraction and treatment would continue for at least 25 years.

### **2.4.4 Scoping Treatment Options**

Two treatment options were considered for the pump and treat treatment facility. These treatment options are an ex-situ bioreactor to degrade nitrate and an ion exchange process to remove nitrate. These treatment options are described in Appendix C along with advantages and disadvantages of each. Both have considerable disadvantages and would require significant commitment of resources to maintain. Both treatment units also produce waste streams that will need to be disposed of.

## **2.5 *Summary of Technology Descriptions***

Based on the technical descriptions of the remedial alternatives presented in this section, the six remedial alternatives stated in the CME Work Plan for BSG (SNL/NM 2004a) have been reduced to:

1. Groundwater monitoring,
2. MNA,
3. ISB, and
4. Pump and treat.

In summary, this new list of remedial alternatives was determined based on information in the technology descriptions. No changes were made to the first two remedial alternatives. The treatment methods for remedial alternatives containing ISB and pump and treat were defined, and because implementation of ISB or pump and treat would treat nitrate to applicable standards, a separate technology following completion would not be required.

### 3.0 REMEDIAL ALTERNATIVE CONCEPTUAL DESIGNS

The purpose of this section is to present conceptual designs of the remedial alternatives based on the technology descriptions presented in Section 2.0. The conceptual designs provide information for performing a remedial alternative evaluation and will be updated as laboratory and field studies provide more information. Conceptual designs for each remedial alternative include an overview of the remedial alternative, a description of the T&FRs, and a list of the expected costs for each remedial alternative. The expected duration of each remedial alternative is addressed as it relates to other remedial alternatives. A duration of 30 years will be used when cost is estimated for remedial alternatives.

#### 3.1. Groundwater Monitoring

Groundwater monitoring would continue as described in Section 2.1. Figure 3-1 illustrates the process of implementing groundwater monitoring.

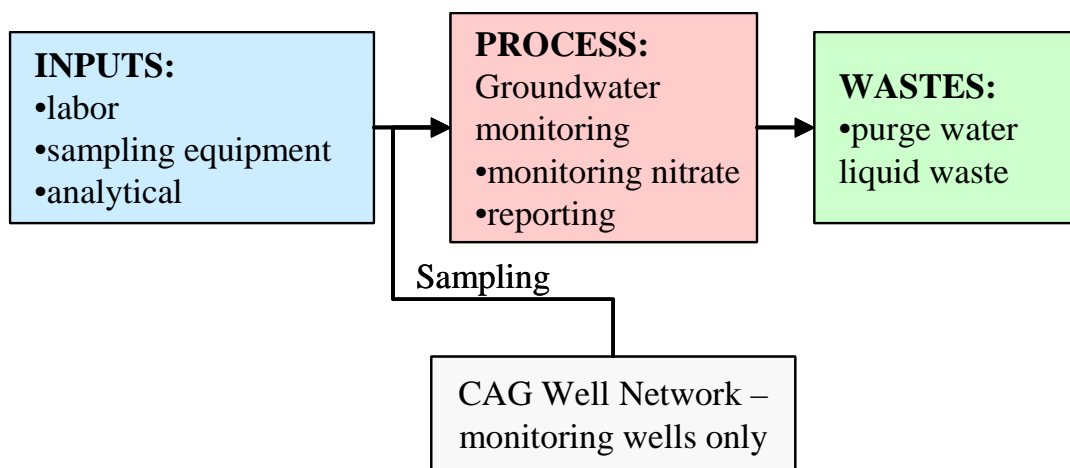


Figure 3-1. Process diagram for groundwater monitoring.

##### 3.1.1 Technical and Functional Requirements

Implementation of this approach requires the ability to monitor the contaminant (nitrate) in groundwater. This requires that the existing monitoring well network be maintained. This monitoring would need to occur until it can be demonstrated that nitrate concentrations are below MCLs. This would require no detections of nitrate above the MCL of 10 mg/L in monitoring wells for a period of time to be determined in the implementation work plan. Table 3-1 details the T&FRs.

Assumptions include:

- It can be determined during the CME that there is no risk to potential receptors.
- A sufficient monitoring well network exists.

Table 3-1. T&FRs for groundwater monitoring remedial alternative.

Parameter	Requirement
Duration of groundwater monitoring	A remedy duration was not determined as part of the data gaps review. Monitoring would be conducted throughout the duration of the remedy.
Frequency of groundwater monitoring	Annual
Analytes/field parameters	Nitrate, water levels
Reporting	Annual reporting during performance operations may be annual or every 5 years for long-term operations.
Equipment	All equipment necessary for monitoring, including pumps, sample bottles, power (generator or utilities), shipping supplies, purge water tanks, personal protection equipment, and any other necessary equipment.
Equipment storage	Storage for field sampling and waste containing equipment.
Waste storage	Storage of purge water until authorized to dispose.
Institutional controls	Institutional controls would consist of engineering and administrative controls to protect current and future users from health risks associated with contaminated groundwater. Engineering controls would include methods to restrict access to contaminated water, including locking devices on wellheads. Administrative controls would include postings on wellheads identifying potential hazards and placement of written notification of this corrective measure in the facility land-use master plan.

### 3.1.2 Cost

Cost elements to be considered for implementing groundwater monitoring for nitrate include capital equipment and operations and maintenance costs, as outlined in Table 3-2.

Table 3-2. Itemized cost elements for the groundwater monitoring remedial alternative.

Capital	Operations and Maintenance
<ul style="list-style-type: none"> <li>Costs associated with designing a long-term groundwater monitoring program</li> <li>Indirect costs (legal and permitting fees)</li> </ul>	<ul style="list-style-type: none"> <li>Costs of maintaining an adequate monitoring well network for the duration of the remedy</li> <li>Sampling and analyses costs</li> <li>Reporting costs for the duration of the remedy</li> <li>Indirect operational costs including institutional controls, contingency allowances, and administrative costs</li> </ul>

## 3.2 Monitored Natural Attenuation

Implementation of this remedial alternative would consist of characterization and monitoring of natural attenuation mechanisms and monitoring attenuation of contaminants in the subsurface without active remediation. The general approach and mechanisms for MNA are described in Section 2.2. Figure 3-2 illustrates the process of implementing MNA for BSG.

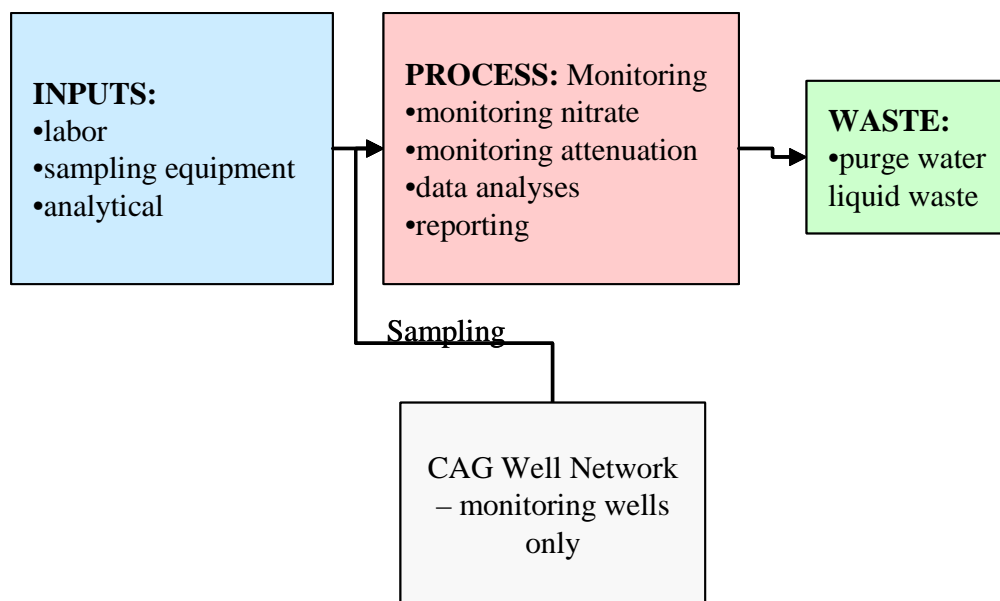


Figure 3-2. Process diagram for MNA.

### 3.2.1 Technical and Functional Requirements

Implementation of this approach must allow monitoring of contaminant attenuation mechanisms in the subsurface and the contaminant plume. This entails monitoring nitrate concentrations and parameters to monitor attenuation mechanisms (i.e., redox parameters or dissolved gases). This monitoring would need to continue for the duration of the remedy. Table 3-3 details the T&FRs.

Assumptions include:

- The CME demonstrates that there is no unacceptable risk to potential receptors,
- Monitoring would not continue for longer than 30 years,
- Natural attenuation mechanisms are identified,
- Necessary equipment, utilities, and personnel are available, and
- A sufficient monitoring well network exists.

Table 3-3. T&FRs for MNA remedial alternative.

Parameter	Requirement
Duration of monitoring	A remedy duration was not determined as part of the data gaps review. Monitoring would be conducted throughout the duration of the remedy.
Frequency of monitoring	Annual
Analytes/ field parameters	All nitrate, water levels, and other parameters necessary to monitor attenuation mechanisms.
Analyses	The groundwater monitoring data would be analyzed and interpreted. These data would be used to monitor attenuation mechanisms and track COC concentration changes.
Reporting	Annual reporting during performance operations, followed by reporting every 5 years until the end of long-term operations. Reports would include analysis of concentration trends and comparison to predicted trends of attenuation.
Equipment	All equipment necessary for monitoring, including pumps, sample bottles, power (generator or utilities), shipping supplies, purge water tanks, personal protection equipment, and any other necessary equipment.
Equipment storage	Storage for field sampling and waste containing equipment.
Waste storage	Storage of purge water until authorized to dispose.
Institutional controls	Institutional controls would consist of engineering and administrative controls to protect current and future users from health risks associated with contaminated groundwater. Engineering controls would consist of methods to restrict access to contaminated water, including locking devices on wellheads. Administrative controls would include postings on wellheads identifying potential hazards and placing written notification of this corrective measure in the facility land-use master plan.

### 3.2.2 Cost

Costs of implementing MNA would include capital equipment and operations and maintenance costs as listed in Table 3-4.

Table 3-4. Itemized cost elements for the MNA remedial alternative.

Capital	Operations and Maintenance
<ul style="list-style-type: none"> <li>Costs associated with designing a long-term groundwater monitoring program</li> <li>Costs of characterizing natural attenuation</li> <li>Indirect costs (legal and permitting fees)</li> </ul>	<ul style="list-style-type: none"> <li>Costs of maintaining an adequate monitoring well network for the duration of the remedy</li> <li>Sampling and analyses costs</li> <li>Reporting costs for the duration of the remedy</li> <li>Costs for data analyses and interpretation</li> <li>Indirect operational costs, including institutional controls, contingency allowances, and administrative costs</li> </ul>

### 3.3 In Situ Bioremediation

Application of this remedial alternative for BSG would have the purpose of inducing a biologically reduced zone that encompasses the nitrate-contaminated groundwater. Figure 3-3 illustrates the process of implementing ISB.

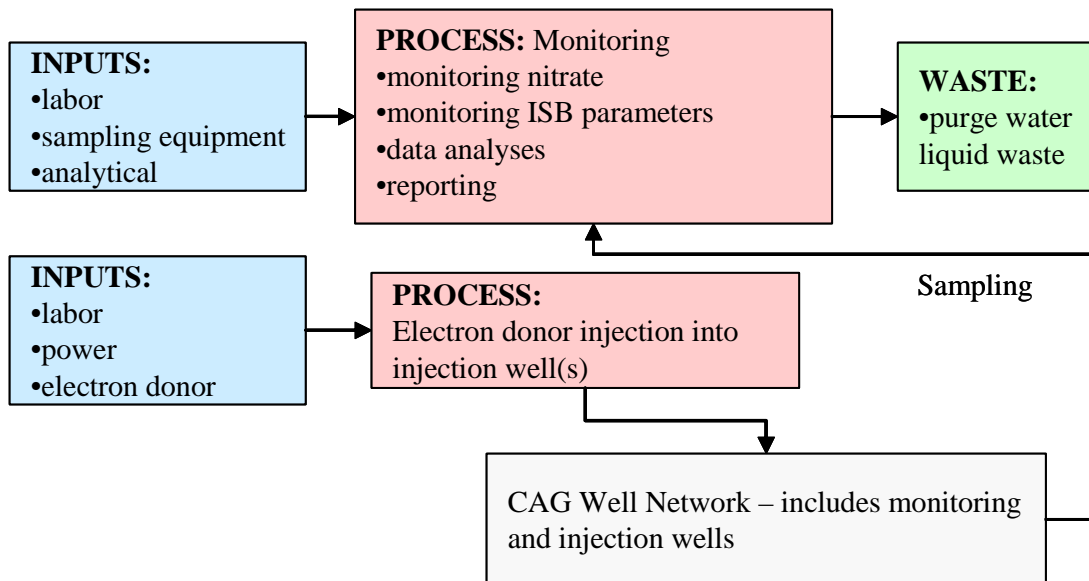


Figure 3-3. Process diagram for ISB.

#### 3.3.1 Technical and Functional Requirements

Implementation of this remedial alternative would require creating a biologically reduced zone in the BSG to remediate groundwater containing nitrate by inducing denitrification. The electron donor addition system must emplace enough electron donor to reduce oxygen and nitrate. This system would be composed of electron donor injection wells and would include electron donor injection equipment. Table 3-5 lists the T&FRs for this remedial alternative.



Table 3-5. T&FRs for ISB remedial alternative.

Parameter	Requirement
Remedy duration	If distribution of electron donor is achieved, implementation may require significantly less time than the other remedial alternatives considered.
Injection operations duration	Distribution of electron donor to the BSG may only need to occur once. However, distributing the electron donor over such a large volume in a poorly connected fractured bedrock system without displacing contaminants is impractical due to the reasons stated in Section 2.3.2.
Injection wells	Several injection wells will likely be necessary due to difficulties in distributing electron donor over the volume of contaminated aquifer and the lack of hydraulic communication between wells (see Sections 1.3 and 2.3).
Injection equipment	Injection equipment will include a water supply (tanks or pumping from the Burn Site Well), mixing equipment, and other necessary plumbing and equipment.
Duration of monitoring	Monitoring would occur during injections. It is estimated that monitoring would continue at a reduced frequency for several years after the beginning of remedy implementation.
Frequency of monitoring	Monitoring of groundwater would increase in frequency in all wells during and for a short period of time after the sodium lactate injection(s). Monitoring would occur annually until it is confirmed that clean-up goals have been achieved.
Analytes/ field parameters	Nitrate, water levels, parameters necessary to monitor ISB operations (i.e., chemical oxygen demand to monitor electron donor distribution and utilization).
Analyses	The groundwater monitoring data would be analyzed and interpreted. Data would be used to track the performance of ISB and monitor contaminant reduction.
Reporting	Annual reports that would include analysis of concentration trends and ISB performance.
Sampling equipment	All equipment necessary for monitoring, including pumps, sample bottles, power (generator or utilities), shipping supplies, purge water tanks, personal protection equipment, and any other necessary equipment.
Equipment storage	Storage for field sampling and waste containing equipment
Waste storage	Storage of purge water until authorized to dispose.
Institutional controls	Institutional controls would consist of engineering and administrative controls to protect current and future users from health risks associated with contaminated groundwater. Engineering controls would consist of methods to restrict access to contaminated water, including locking devices on wellheads. Administrative controls would include postings on wellheads identifying potential hazards and placing written notification of this corrective measure in the facility land-use master plan.

Assumptions include:

- Necessary equipment, utilities, and personnel are available,
- A denitrifying microbial community can be induced by addition of electron donor, and
- Distribution of electron donor to the contaminated groundwater can be achieved.

### 3.3.2 Cost

Cost elements for implementing ISB would include capital and operations and maintenance costs, as listed in Table 3-6.

Table 3-6. Itemized cost elements for the ISB remedial alternative.

Capital	Operations and Maintenance
<ul style="list-style-type: none"><li>• Engineering costs to design ISB implementation</li><li>• Construction of injection well(s)</li><li>• Construction of injection equipment.</li><li>• Indirect costs (legal and permitting fees)</li></ul>	<ul style="list-style-type: none"><li>• Includes labor, material, and equipment costs to inject</li><li>• Sampling and analyses costs (sampling and analyses may be more extensive to monitor redox conditions)</li><li>• Reporting costs for the duration of the remedy (the remedy may require less time and fewer reports)</li><li>• Costs for data analyses and interpretation</li><li>• Indirect operational costs including institutional controls, contingency allowances, and administrative costs</li></ul>

### 3.4 *Pump and Treat*

Application of this remedial alternative for BSG would involve extraction of contaminated groundwater and treatment of the water to remove or degrade nitrate. The water would be extracted sufficiently long to remove contaminants in the aquifer to below MCLs. Figure 3-4 illustrates the process of implementing pump and treat.

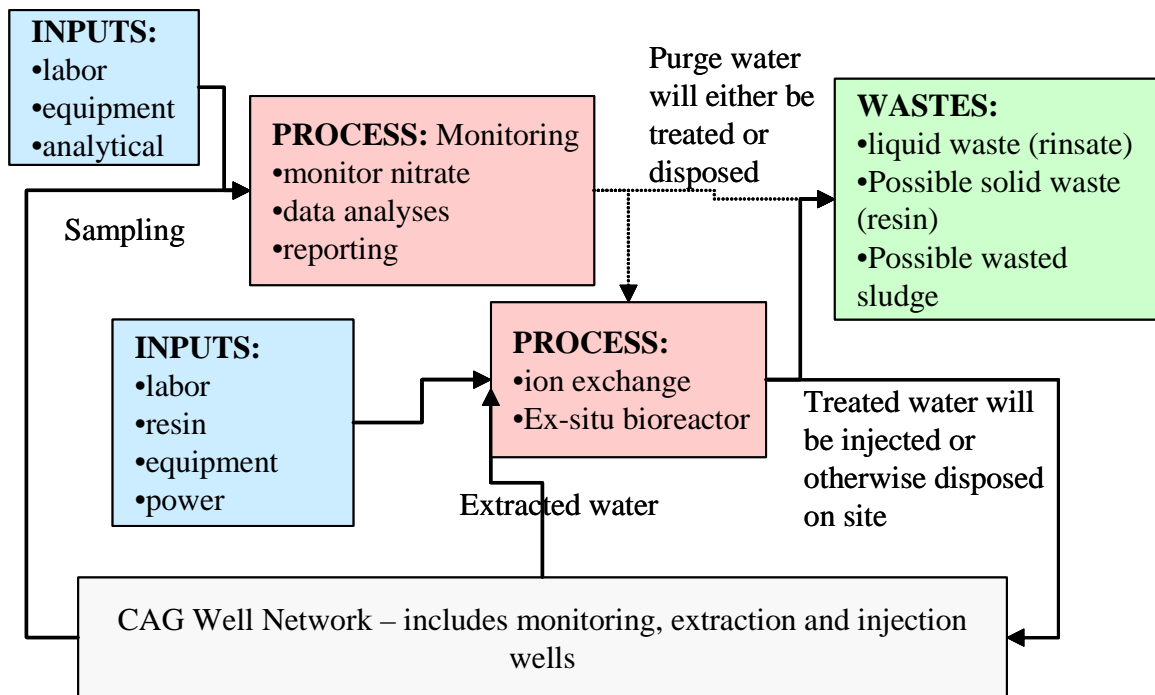


Figure 3-4. Process diagram for implementation of pump and treat.

### 3.4.1 Technical and Functional Requirements

Implementation of this remedial alternative would require pumping of contaminated groundwater to the surface, treating the water for nitrate to concentrations below clean-up goals, and disposing the water. The system would be composed of extraction wells, a treatment facility, and, depending on the disposal option chosen, may also require an injection well. Table 3-7 illustrates the T&FRs for this remedial alternative.

Assumptions include:

- Necessary equipment, utilities, and personnel are available,
- A sufficiently large capture zone can be created downgradient of the contamination to capture the entire width of nitrate-contaminated water, and
- The treatment facility would be able to treat nitrate to below MCLs.

### 3.4.2 Cost

Costs of implementing pump and treat would include capital and operations and maintenance costs, as listed in Table 3-8.

Table 3-7. T&FRs for pump and treat remedial alternative.

<b>Parameter</b>	<b>Requirement</b>
Extraction well(s)	Extraction well(s) would be constructed that penetrate and are screened across the contaminated zone of the aquifer. The extraction well(s) would be placed downgradient of well CYN-MW1D.
Treatment facility	The treatment facility building would be composed of a modified sea-van, equipped with electric power.
Treatment equipment	Depending on the treatment option implemented, would require an ion exchange unit complete with plumbing or a biological treatment unit with associated pumps and equipment.
Extraction rate	Extraction rate may range from less than 1 to over 100 gpm.
Pump and treat duration	Preliminary estimates suggest that a minimum duration of extraction operations would be 25 years. Treatment would need to occur as long as groundwater is being extracted.
Duration of monitoring	Groundwater monitoring would continue throughout pumping operations and for a period of 5 years following or until clean-up objectives are achieved.
Frequency of monitoring	Regular monitoring of treatment facility influent, effluent and intermediate sampling ports would be required. Groundwater monitoring would also occur regularly.
Analytes/ field parameters	All nitrate and water levels must be monitored.
Analyses	The groundwater monitoring data would be analyzed and interpreted. Data would be used to track the performance of Pump and Treat and monitor contaminant reduction.
Reporting	Annual reports that would include analysis of concentration trends and comparison to predicted trends of attenuation.
Sampling equipment	All equipment necessary for monitoring, including pumps, sample bottles, power (generator or utilities), shipping supplies, purge water tanks, personal protection equipment, and any other necessary equipment.
Equipment storage	Storage for field sampling and waste containing equipment
Institutional controls	Institutional controls would consist of engineering and administrative controls to protect current and future users from health risks associated with contaminated groundwater. Engineering controls would consist of methods to restrict access to contaminated water, including locking devices on wellheads. Administrative controls would include postings on wellheads identifying potential hazards and placing written notification of this corrective measure in the facility land-use master plan.

Table 3-8. Itemized cost elements for the pump and treat remedial alternative.

Capital	Operations and Maintenance
<ul style="list-style-type: none"> <li>• Engineering costs</li> <li>• Construction of extraction well(s). May also include construction of an injection well.</li> <li>• Construction of treatment facility and installation of treatment equipment.</li> <li>• Indirect costs (legal and permitting fees)</li> </ul>	<ul style="list-style-type: none"> <li>• Costs associated with operations and maintenance of the extraction system and treatment facility</li> <li>• Sampling and analyses costs. In addition to monitoring groundwater sampling and analyses would also include monitoring influent, effluent and other water samples from the treatment facility</li> <li>• Disposal of secondary waste (i.e. concentrated nitrate brine waste in spent resin from ion exchange)</li> <li>• Costs for data analyses and interpretation</li> <li>• Reporting costs for the duration of the remedy</li> <li>• Indirect operational costs including institutional controls, contingency allowances, and administrative costs</li> </ul>

## 4.0 REMEDIAL ALTERNATIVE EVALUATION

The remedial alternative conceptual designs provided in this paper summarize implementation strategies for remedial alternatives to support a remedial alternative evaluation. The remedial alternative evaluation is intended to identify remedial alternatives that should be investigated through laboratory and field studies. Each remedial alternative is evaluated using the threshold and remedial alternative criteria, as stated in the CME Work Plan for BSG (SNL/NM 2004a). The outcome of this evaluation is a list of remedial alternatives that pass the evaluation and recommendations of additional studies to fill data gaps identified for those remedial alternatives.

### 4.1 Threshold Criteria Evaluation

As specified in the COOC (NMED 2004), each remedial alternative must be evaluated based on the threshold criteria. Descriptions of the threshold criteria are stated in the CME Work Plan for BSG (SNL/NM 2004a). The following threshold criteria were evaluated:

- Protect human health and the environment,
- Attain media cleanup standard or alternative, approved risk-based cleanup goals, and
- Comply with standards for management of wastes.

As discussed in the Burn Site Current Conceptual Model (SNL/NM 2004b), there is no point source of nitrate; therefore, the source control threshold criterion was not evaluated. Remedial alternative conceptual design information was used to determine if the remedial alternative meets the threshold criterion. This evaluation was a YES/NO evaluation. The results of this evaluation are presented in Table 4-1. As demonstrated, all of the remedial alternatives received a YES rating for each of the three categories.

Table 4-1. Threshold criteria evaluation.

Remedial Alternatives	Protective of Human Health and Environment	Attain Media Cleanup Standards	Waste Management Standards Compliance
Groundwater monitoring	Yes	Yes	Yes
MNA	Yes	Yes	Yes
ISB	Yes	Yes	Yes
Pump and treat	Yes	Yes	Yes

YES = the remedial alternative meets the threshold criterion

NO = the remedial alternative does not meet the threshold criterion

Note: The threshold criterion, *Source Control*, is not included since a point source of release is not present for BSG.

## 4.2 Remedial Alternative Evaluation

Because all remedial alternatives passed the threshold criteria evaluation, they were evaluated based on the remedial alternative evaluation criteria. The remedial alternative evaluation criteria are described in the CME Work Plan for BSG (SNL/NM 2004a). As specified in the COOC (NMED 2004), the remedial alternative evaluation must be balanced and includes the following:

- Long-term reliability and effectiveness,
- Reduction of toxicity, mobility, or volume,
- Short-term effectiveness,
- Feasibility,
- Capital cost, and
- Operations and maintenance cost.

The remedial alternative conceptual design information was used to perform a comparative analysis for each remedial alternative using the remedial alternative threshold criteria. The comparative analysis was performed using the following ratings:

“Not effective”	=	Does not effectively meet the remedial alternative criterion within a timeframe that is comparable to other remedial alternatives,
“+”	=	Effectively meets the remedial alternative criterion, and
“+ +”	=	More effectively meets the remedial alternative criterion.

The total number of pluses represents how effectively the remedial alternative meets the criterion. A “Not effective” rating receives no score. Therefore, with six categories, the possible scores range from 0 – 12. This approach balances the criteria in order to evaluate each remedial alternative in a simple, comparative manner. Information supporting comparative analysis of the remedial alternatives is presented in Table 4-2, and the results of the analyses are presented in Table 4-3. The supporting information states a rationale for the comparative analysis rating assigned to each remedial alternative for each criterion. This includes comparison of remedial alternatives and identifying data gaps. Data gaps are identified where additional information is needed to accurately rate the criterion and this information can be collected in a cost- and time-efficient manner.

The comparative analyses shown in Table 4-3 demonstrate that the ISB and pump and treat remedial alternatives were considerably less effective than the other two remedial alternatives. For ISB, it would not be feasible to distribute electron donor in bedrock over this large nitrate contaminated area (approximate length of the contaminated groundwater plume is 4,000 ft) without displacing the nitrate-contaminated water. Although, the pump and treat remedial alternative may be effective for containment of the plume and removal of nitrate from extracted groundwater, this remedial alternative will not be effective for concentration reduction in groundwater and aquifer restoration. The contamination will be transferred to a different media (i.e. resin used in ion exchange) instead of being destroyed in situ, and additional costs will include disposing of concentrated nitrate brine waste and the spent resin.

Table 4-2. Information supporting comparative analysis of the remedial alternatives.

Remedial Alternatives	Long-Term Reliability and Effectiveness	Reduction of Toxicity, Mobility, or Volume	Short-Term Effectiveness	Feasibility	Cost	
					Capital	Operations and Maintenance
Groundwater monitoring	Data gap. The CME process must demonstrate that there is no risk to receptors without considering degradation. If it is demonstrated that there is no long-term risk in leaving contaminants in place, then the remedy is effective because the process of monitoring groundwater is reliable and is effective at tracking contaminants.	Would not consider toxicity reduction.	There is no immediate reduction in contaminant concentration, short-term risk is less than pump and treat where contaminants are brought to the surface.	Ready to implement immediately.	Costs less to implement than more active remedies.	The timeframe of continued monitoring may be longer than more active remedial alternatives.
MNA	Data gap. If the CME demonstrates that natural attenuation mechanisms are operable, then this remedial alternative will be effective.	Data gap. Need to confirm or characterize background nitrate concentrations and know if there is a remaining source of nitrate.	There is no immediate reduction in contaminant concentration, short-term risk is less than pump and treat where contaminants are brought to the surface.	Ready to implement immediately.	Costs less to implement than more active remedies	The timeframe of continued monitoring may be longer than more active remedial alternatives.



Table 4-2. (continued).

Remedial Alternatives	Long-Term Reliability and Effectiveness	Reduction of Toxicity, Mobility, or Volume	Short-Term Effectiveness	Feasibility	Cost	
					Capital	Operations and Maintenance
ISB	Successful implementation of ISB will degrade contaminants and remove long-term risk of exposure. However, there is also a risk that groundwater containing contaminants will be displaced by injected electron donor.	Reduces toxicity in situ, by degrading nitrate. However, there is also a risk that water containing contaminants will be displaced by injected electron donor solution.	Reduces contaminant concentrations with minimal short-term risk from bringing contaminants to the surface.	Achieving effective distribution of the electron donor without displacing contaminants is not feasible due to the non-sorbing nature of nitrate, the size of the plume, and the nature of the fractured bedrock aquifer.	Requires construction of several new wells and injection equipment.	Requires purchase of large amounts of electron donor, and intensive operations.
Pump and treat	A pump and treat system may not be reliable to remove contaminants and restore the aquifer. It is estimated that the remedial timeframe will require active operations for a long period of time.	It may be difficult to extract contaminants from the aquifer, and if ion exchange is used contaminants are transferred to a different media instead of destroyed in groundwater.	There may be an immediate reduction in concentration, but contaminants are brought to the surface increasing risk of exposure.	Will require a long period of operation	Requires well drilling and construction of infrastructure.	Operation duration could be very long requiring considerable cost in maintaining a treatment system and pumping wells.

Table 4-3. Comparative analysis of remedial alternatives for BSG.

Remedial Alternatives	Long-Term Reliability and Effectiveness	Reduction of Toxicity, Mobility, or Volume	Short-Term Effectiveness	Feasibility	Cost		
					Capital	Operations and Maintenance	
Groundwater monitoring	++	Not Effective	+	++	++	+	<b>Totals</b> 8
MNA	++	+	+	++	++	+	9
ISB	++	+	++	Not effective	Not effective	Not effective	5
Pump and treat	Not effective	+	+	+	+	Not effective	4

As discussed in the CME Work Plan for BSG (SNL/NM 2004a), if a remedial alternative is determined to be significantly less effective than the other remedial alternatives, then it will no longer be considered. Therefore, the pump and treat and ISB remedial alternatives will no longer be considered.

While ISB and pump and treat remedial alternatives would not be effective, the analyses demonstrated that the other two remedial alternatives are comparable to each other in effectiveness and cost. Small changes in rankings will not significantly change the overall score of the remedial alternatives. The two remaining remedial alternatives are still considered suitable for implementation for BSG but have different strengths and weaknesses, and will continue to be evaluated.

### ***4.3 Summary of the Remedial Alternative Evaluation***

Based on the information presented in this data gap review, the list of remedial alternatives to be considered in data gathering activities has been revised three times, as shown in Figure 4-1. The initial list of six was identified in the CME Work Plan for BSG (SNL/NM 2004a). This list was reduced to four as discussed in Section 2.0. Following the remedial alternative evaluation, the list was further reduced to two remedial alternatives that will be evaluated by conducting further studies.

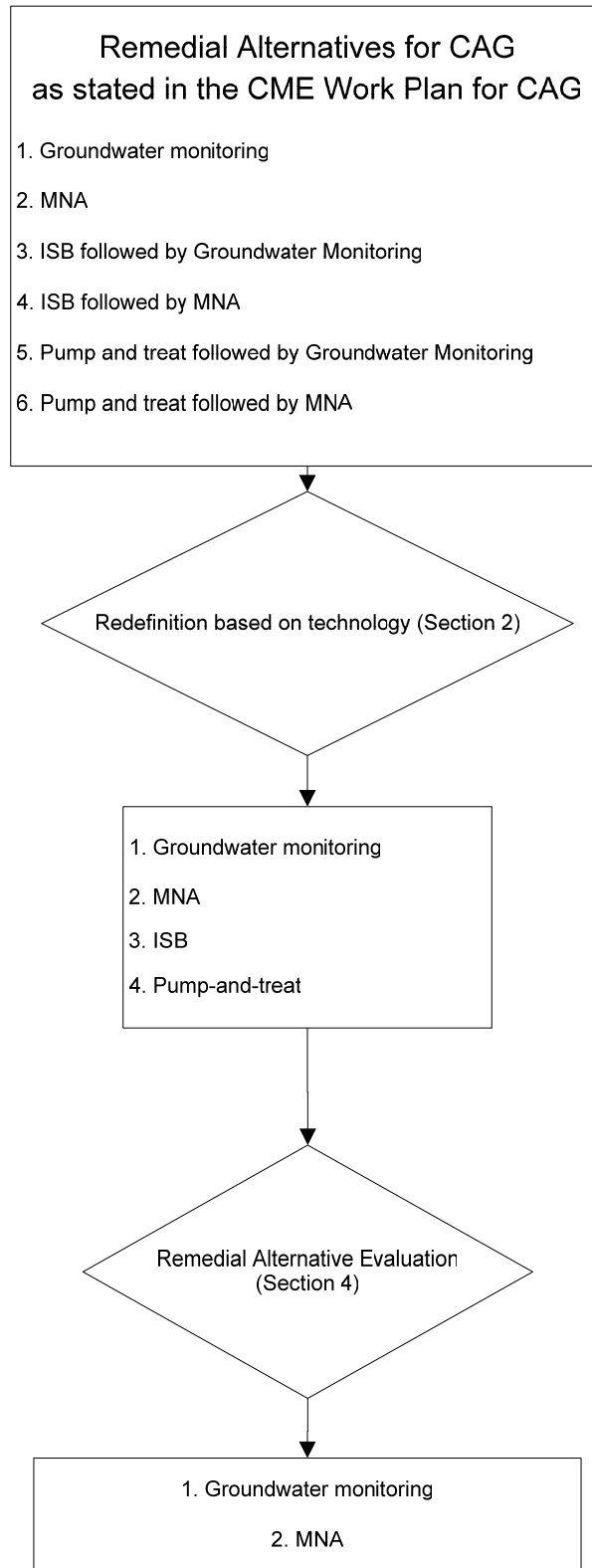


Figure 4-1. Changes in remedial alternatives for BSG.

## **5.0 RECOMMENDATIONS FOR FURTHER STUDIES**

Data gaps regarding individual implementation and application of remedial alternatives to BSG have been identified. Each of several potential laboratory or field scale studies identified to provide this information were considered based on the results of the remedial alternative evaluation. A decision was made regarding the utility of performing each of these studies considering the data gaps identified and the remedial alternative evaluation outcome. Table 5-1 presents specific activities and whether the activity will be performed. These activities correspond to stages of data gathering activities identified in the CME Work Plan for BSG (SNL/NM 2004a). Based on the information and evaluation of remedial alternatives presented in this report, field studies for groundwater monitoring and MNA will be conducted. However, the following studies will not be conducted based on this information:

- Laboratory and field studies for ISB, and
- Field studies for pump and treat.

### **5.1 *Field Studies for Groundwater Monitoring and MNA***

Field studies for groundwater monitoring and MNA will include additional sampling of spring water and soil. Activities will be conducted to establish background nitrate concentrations in soil and spring water and to determine if non-point nitrate sources are still present. Evaluation of nitrate in sediments from nearby pristine alluvial deposits and upgradient springs discharging from fractured bedrock will be useful in defining the source of nitrate in groundwater at the Burn Site and evaluating whether that potential nitrate source has been depleted. Both near surface and deep soil borings will be collected and analyzed for nitrate, high explosives compounds, and other analytes.

The results of these field studies will be used to evaluate the two remedial alternatives, groundwater monitoring and MNA. The results will be used to fill the data gaps identified during the paper study, including the presence or absence of a nitrate source in the vadose zone and establishing a background nitrate concentration. The results will be included in an informal report for project review and will ultimately support preparation of the CME report.

### **5.2 *Activities No Longer Considered***

Several laboratory and field scale activities were initially identified to fill anticipated data gaps regarding the ISB and pump and treat remedial alternatives. These included bench scale microcosm studies and field scale injection tests for ISB and aquifer tests for pump and treat. A brief description of these activities is included in Table 5-1. It has been determined that the ISB and pump and treat remedial alternatives are significantly less effective than MNA or groundwater monitoring for the reasons stated in Section 4.0, and they will no longer be considered as remedial alternatives for the CME. Therefore, these laboratory and field studies are no longer necessary.

Table 5-1. Recommended field and laboratory studies.

Stage (Remedial Alternative)	Activity/Purpose	Perform?
<u>Field Scale Study</u> (ISB)	Lactate injection demonstration to provide evidence that denitrification can be induced by injecting aqueous electron donor and to provide estimates for injection rate, injection frequency, and other design estimates for full-scale implementation.	<b>No.</b> The ISB remedial alternative is no longer being considered.
<u>Laboratory Study</u> (ISB)	Laboratory studies to determine if denitrifying organisms are present in BSG and/or if denitrification can be induced.	<b>No.</b> The ISB remedial alternative is no longer being considered.
<u>Field Scale Study</u> (Groundwater Monitoring and MNA)	Spring water, near surface soil, and deep borehole soil sampling to determine if there is a source of nitrate in the vadose zone and if background nitrate concentrations are similar to concentrations in BSG.	<b>Yes (in progress).</b> Will be completed as stated in the <i>Sampling and Analysis Plan -Burn Site Groundwater Nitrate Source Evaluation</i> .
<u>Field Scale Study</u> (Pump and treat)	Aquifer tests to determine pumping rates in a new extraction well for a pump and treat system and provide more information on aquifer properties.	<b>No.</b> The pump and treat remedial alternative is no longer being considered.

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**APPENDIX A**  
**ESTIMATION OF SPECIFIC CAPACITIES**



## A-1. Estimation of Specific Capacities

During groundwater sampling, the water level in the sampled well was measured and the volume pumped was recorded at intervals during well purging prior to sampling. These measurements were compiled from three recent sampling events (March 2003, June 2003, and December 2003). Relative drawdown was calculated as the difference between an initial water level reading prior to pumping and the corresponding water level at the time being measured. Using these parameters, specific drawdown was calculated for the last three measurements prior to sampling. As demonstrated in Table A-1 the estimated specific capacity in a new well might be expected to range from 0.03 to 33.33 gpm/ft of drawdown.

Table A-1. Calculated specific capacities of Burn Site wells.

	<b>Specific Capacity (gpm/ft of drawdown)</b>		
	<b>March 2003</b>	<b>June 2003</b>	<b>December 2003</b>
CYN-MW1D	0.12	0.12	0.21
CYN-MW3	9.72	9.72	33.33
CYN-MW4	0.07	0.03	0.09

## **APPENDIX B**

### **SCOPING ESTIMATES OF OPERATIONS AND TIMEFRAME FOR PUMP AND TREAT**

## B-1. Capture Zone Analyses

The estimation method is adopted from *Elements for Effective Management of Operating Pump and Treat Systems* (EPA 2002). Equations 1 and 2 were used to calculate extraction flow rates and capture zone widths shown in Table B-1.

$$W = \frac{Q}{C \times B \times K \times i} \quad (1)$$

$$Q = W \times B \times C \times K \times i \quad (2)$$

where:

W	=	capture zone width (ft)
Q	=	extraction rate (gpm)
C	=	volume conversion factor (7.481 gal/ft <sup>3</sup> )
B	=	saturated thickness (ft)
K	=	hydraulic conductivity (ft/min)
i	=	hydraulic gradient (ft/ft).

For most of the input parameters, a range of values is available that may be representative of the aquifer or well. Therefore, a high and a low value were chosen for each parameter and the calculations were performed for every possible combination of these variables. Capture zone width was calculated assuming that extraction would occur at the maximum possible flow rate. In some cases the capture zone width was very large and the maximum flow rate was impractical to maintain. Therefore, the necessary flow rate to achieve a capture zone width of 2,000 ft was also calculated to demonstrate what a reasonable flow rate might be. Other assumptions and parameter values are:

1. The horizontal hydraulic conductivity ( $K_h$ ) ranges from 0.01 to 1 ft/day (SNL/NM 2004b).
2. Vertical flow is negligible (SNL/NM 2004b).
3. The screened interval ranges from 50 to 100 ft. The vertical extent of the contamination is unknown, however nitrate has been detected consistently in CYN-MW1D, which is screened more than 50 ft below the water table. This range of screened intervals was chosen for estimating purposes, however it may be necessary to extract from a larger interval of the saturated zone.
4. The horizontal hydraulic gradient ( $i$ ) ranges from 0.07 to 0.14 ft/ft (SNL/NM 2004b).

5. The aquifer is homogenous and isotropic. This assumption is necessary for this approach; however, the aquifer may not be homogenous or isotropic within the capture zone.
6. The well is pumped continuously.
7. Water level can be drawn down to within 5 ft of the bottom of the screened interval.
8. There is no recharge.

Table B-1 demonstrates that it would be feasible to install an extraction system that would capture the contaminant plume as it moves past a downgradient location. In cases where the hydraulic gradient is 1 ft/day and the specific capacity is 0.05 gpm/ft of drawdown, it would not be possible to create sufficient capture zone with a single well and multiple wells would need to be constructed. In all other cases, it would be possible to use a single extraction well. Extraction flow rates might range from less than 1 gpm to over 100 gpm. If an extraction system were to be designed, more site characterization would be necessary before constructing extraction wells.

## **B-2. Extraction Duration**

The extraction of groundwater from this downgradient location would need to occur continuously until the nitrate plume has moved into the extraction location. It is assumed that the distance the plume would need to travel is at least 4,000 ft (see Section 1.4.2) and that the minimum transport velocity is 160 ft/yr (SNL/NM 2004b). Therefore, continuous pumping and treating operations would need to occur for at least 25 years.

Table B-1. Estimation of capture zone widths and flow rates.

Hydraulic Gradient (ft/ft)	Hydraulic Conductivity (ft/day)	Specific Capacity, (gpm/ft of drawdown)	Screened Interval (ft)	Capture Zone Depth (ft)	Maximum Extraction Rate (Q) (gpm)	Capture Zone Width (W) (ft)	Pumping Rate, (W=2,000 ft) (gpm)
0.07	0.01	0.05	50	50	2.25	12,375	0.36
0.14	0.01	0.05	50	50	2.25	6,188	0.73
0.07	1	0.05	50	50	2.25	124	>maximum pump rate
0.14	1	0.05	50	50	2.25	62	>maximum pump rate
0.07	0.01	35	50	50	1575	8,662,500	0.36
0.14	0.01	35	50	50	1575	4,331,250	0.73
0.07	1	35	50	50	1575	86,625	36.36
0.14	1	35	50	50	1575	43,313	72.73
0.07	0.01	0.05	100	100	4.75	13,063	0.73
0.14	0.01	0.05	100	100	4.75	6,531	1.45
0.07	1	0.05	100	100	4.75	131	>maximum pump rate
0.14	1	0.05	100	100	4.75	65	>maximum pump rate
0.07	0.01	35	100	100	3325	9,143,750	0.73
0.14	0.01	35	100	100	3325	4,571,875	1.45
0.07	1	35	100	100	3325	91,438	72.73
0.14	1	35	100	100	3325	45,719	145.45

**APPENDIX C**

**TREATMENT OPTIONS FOR PUMP AND TREAT**

## **C-1. Treatment Options for Pump-and-Treat**

This appendix provides details for ex-situ treatment options that would be considered for implementation of pump and treat. One of these technologies may be applied if a remedial alternative involving pump and treat is chosen as the preferred remedial alternative for BSG. The following sections provide details on two treatment options, including ion exchange and biological treatment.

## **C-2. Ion Exchange Unit for Nitrate Removal**

This option uses ion exchange to remove nitrate from the water. A treatment design is given here to provide estimates on the operating requirements.

### ***Design***

The technology uses anion exchange resins to remove nitrates. The resins are periodically recharged using a salt solution. Qualities of the BSG that may effect implementation of this technology include the presence of sulfate and hardness. The following calculation was performed to demonstrate the effect of sulfate on the ion exchange. The input parameters and assumptions are as follows:

- The resin capacity is 16,000 grains/ ft<sup>3</sup> (from an ion exchange unit manufacturer).
- The range of sulfate concentrations is used from 82 to 180 mg/L. Sulfate has been observed in Canyons groundwater at concentrations ranging from 82.1 mg/L (Nov. 2001 in CYN-MW1D) to 180 mg/L (March 2002 in CYN-MW3) (SNL/NM 2001, SNL/NM 2002, SNL/NM 2003, and SNL/NM 2001c).
- Assumed nitrate concentration is 25 mg/L (as nitrogen). This represents a high range of what might be expected in the treatment system influent (SNL/NM 2004b).

Considering these factors, it was estimated that 1 ft<sup>3</sup> of resin would need to be regenerated after between 317 and 575 gal (depending on the sulfate concentration) of water has been processed. The system size (volume of resin) and regeneration time would be designed based on the flow rate through the system. Flow rate estimates range from 1 to 100 gpm (Appendix B). When considering ion exchange as a treatment technology, it is important to note that even at a flow rate of 1 gpm, a system with 1 ft<sup>3</sup> of resin would need to be regenerated several times a day, and a single regeneration produces several gallons of rinsate salt water requiring disposal.

### ***Advantages and Disadvantages Compared to Other Treatment Options***

Advantages of implementing this treatment design include:

- Low risk of failure and expected to remove nitrate up to 80%.

Disadvantages include:

- Sulfate in BSG will compete with nitrate on the resin.
- Produces a significant concentrated nitrate brine waste stream,
- Regeneration is frequent and will require maintenance, and
- Water hardness and biological activity may interfere with the process.

### **C-3. Biological Treatment**

A biological treatment system would treat nitrate in BSG by degrading it to nitrogen gas. The design presented in this section is a conceptual design provided to demonstrate the inherent advantages and disadvantages in implementing this type of system.

#### ***Design***

The objective of the reactor is to efficiently deplete oxygen and reduce the nitrate to nitrogen gas. An above-ground biological nitrate removal system could be modeled after a plug-flow system utilizing a return activated sludge process (Figure C-1). At the influent electron donor (i.e., sodium lactate) will be continuously added along with return activated sludge. The reactor could consist of 1-ft diameter piping connected in series and arranged in stacks or some other geometry to allow for a sufficient hydraulic retention time while maintaining anaerobic conditions. Following the reactor will be a clarifier to settle sludge and provide return activated sludge to the influent line containing nitrate reducing organisms. Waste streams from this reactor will include waste sludge containing biomass and treated water that may contain organic carbon, dissolved methane, biomass, and potential byproducts of electron donor addition.

#### ***Advantages and Disadvantages***

Advantages of implementing this treatment design include:

- Degrades the nitrate.
- No COC contaminated waste streams will be produced.

The disadvantages include:

- Oxygen in the BSG is a more thermodynamically favorable electron acceptor than nitrate and will increase the necessary retention time and electron donor.
- Continuous pumping of sludge into the return line and wasting of sludge is necessary.
- Waste streams may pose significant difficulties. These will include activated sludge, and treated water containing biomass, COD, and other potential byproducts from the addition of electron donor.
- The system may require large volumes of electron donor.
- Depending on the flow rate, a very large reactor may be necessary to achieve a sufficient retention time.



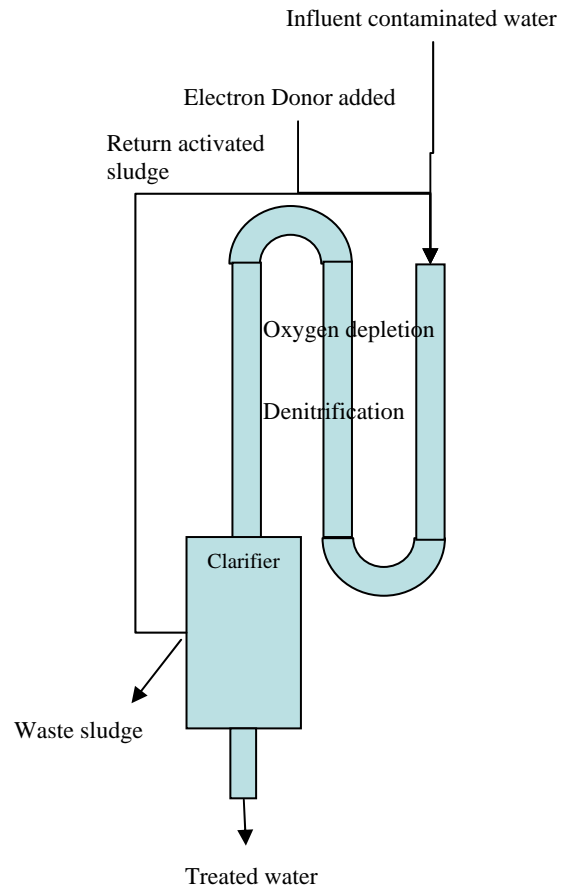


Figure C-1. Biological treatment process.

**Attachment B**

**Nitrate Source Evaluation for  
Burn Site Groundwater**

# **Nitrate Source Evaluation for Burn Site Groundwater at Sandia National Laboratories/New Mexico**

**February 2005**

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## **ABSTRACT**

This document is an informal report of a field-scale study performed as part of the Corrective Measures Evaluation for Burn Site Groundwater at Sandia National Laboratories/New Mexico. An evaluation of the nitrate source in the canyon alluvium was recommended in the “Remedial Alternatives Data Gap Review for Burn Site Groundwater.” This report documents the results of nitrate sampling and analysis in both alluvium and groundwater in the Burn Site area, and presents an interpretation of the data relative to whether the nitrate is derived from natural or anthropogenic sources. The major conclusions of this report are:

- Nitrate in the alluvium and groundwater at the Burn Site is a result of both natural phenomenon and historical Burn Site operations.
- Elevated nitrate concentrations in soil near the Burn Site and in a groundwater plume emanating from the Burn Site are likely the result of historical Burn Site operations, followed by nitrate leaching into the subsurface.
- Nitrate remains in the alluvium at the Burn Site, which is in the vadose zone; however, this nitrate does not represent an active source that would significantly increase nitrate concentrations in groundwater. A conservative estimate indicates that the nitrate remaining in the vadose zone is unlikely to result in groundwater contamination at concentrations higher than have been observed in the past.

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## ACRONYMS AND ABBREVIATIONS

bgs	below ground surface
BH	bore hole
BSG	Burn Site groundwater
CME	Corrective Measures Evaluation
COC	contaminant of concern
COOC	Compliance Order on Consent
CYN	canyon
ft	feet
HE	high explosives
kg	kilogram
L	liter
MCL	maximum contaminant level
mg	milligram
MW	monitoring well
NMED	New Mexico Environment Department
NPN	nitrate plus nitrite
SNL/NM	Sandia National Laboratories/New Mexico
SS	shallow soil
SWMU	Solid Waste Management Unit
TKN	total Kjeldahl nitrogen

## 1.0 INTRODUCTION

The *Corrective Measures Evaluation Work Plan Burn Site Groundwater* (SNL/NM 2004a) was prepared as directed by the Compliance Order on Consent (COOC) issued by the New Mexico Environment Department (NMED) (NMED 2004). The Corrective Measures Evaluation (CME) Work Plan outlines a staged process for evaluation of remedial alternatives. A field studies stage is part of the CME, and this nitrate source evaluation is an informal report of a field study performed to evaluate the source of nitrate in Burn Site groundwater (BSG).

A conceptual model for the Burn Site is also required to implement the CME Work Plan. This conceptual model is presented in the *Current Conceptual Model of Groundwater Flow and Contaminant Transport at Sandia National Laboratories/New Mexico Burn Site* (SNL/NM 2004b). Section 2 of this report presents a summary of the conceptual model.

As part of the paper study stage, the “Remedial Alternatives Data Gaps Review for Burn Site Groundwater” was prepared (SNL/NM 2005a). Recommendations from the paper study resulted in a revised CME process, illustrated in Figure 1.

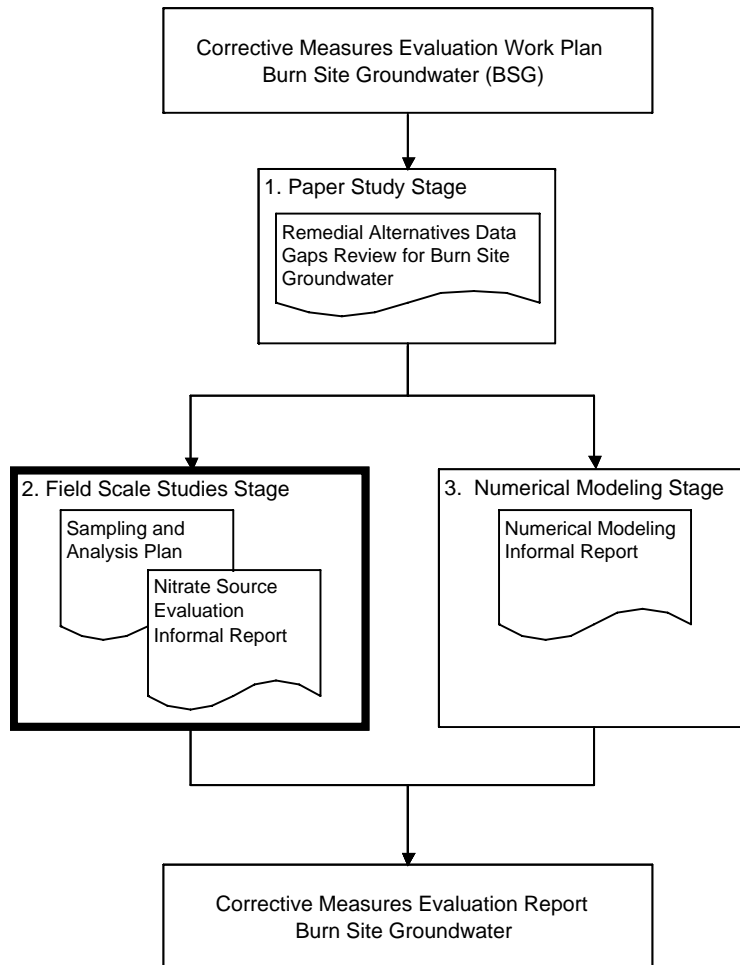


Figure 1. Illustration of the staged process of data gathering activities and production of subsequent reports.

Data gaps identified include determining background nitrate concentrations and evaluating the potential for a residual source of nitrate in the vadose zone. This informal report addresses these data gaps by presenting results and observations (Section 3), interpretation (Section 4), and conclusions (Section 5) of the nitrate source evaluation field study.

This nitrate source evaluation is intended to accomplish the following objectives:

1. Compare background nitrate concentrations in alluvium and groundwater outside of the Burn Site to the nitrate concentrations within the Burn Site and within the BSG nitrate plume, and
2. Evaluate the potential for a continuing source of nitrate in the vadose zone.



## **2.0 CONCEPTUAL MODEL SUMMARY**

Nitrate is the only contaminant of concern (COC) in BSG. Key elements of the Current Conceptual Model of Contaminant Transport at the Burn Site (SNL/NM 2004b) are discussed below. These elements consist of contaminant releases and contaminant transport in groundwater.

### **2.1 Contaminant Releases**

Nitrate is present in BSG at concentrations exceeding the maximum contaminant level (MCL) (10 mg/L as N). This nitrate may be derived either from nitrate residue following open detonation of high explosives (HE) or from concentration of nitrate during evapotranspiration of rainfall that infiltrates the canyon alluvium. Nitrate from either source could accumulate in alluvial deposits in the canyon floor and be mobilized by subsequent wetting events that provide sufficient moisture to infiltrate fracture systems and brecciated fault zones and migrate downward to groundwater flow systems.

### **2.2 Contaminant Transport in Groundwater**

Groundwater in rocks underlying the Sandia National Laboratories/New Mexico (SNL/NM) Burn Site in Lurance Canyon moves as semiconfined fracture flow, eventually discharging to unconsolidated basin-fill deposits in the Albuquerque Basin to the west. Some discharge takes place to springs at the base of the Manzanita Mountains. Local recharge to this low-permeability system occurs through a series of north-trending brecciated fault zones and fractures. These zones provide a permeable conduit between the land surface and the fractured water-bearing rocks at depth.

Water levels and the field of groundwater flow at the Burn Site are described in detail in the Current Conceptual Model for BSG (SNL/NM 2004b). The canyon floor consists of a layer of alluvial fill deposits over bedrock. The depth of the alluvium, as estimated during previous investigations at the Burn Site and the surrounding area, is shown in Figure 2. Groundwater lies some distance below the alluvium in the bedrock. For example, in September 2003 water levels measured in Burn Site wells ranged from 117 ft below ground surface (bgs) at CYN-MW3 to 321 ft bgs at CYN-MW1D (SNL/2004c), while the maximum depth of alluvium is estimated to be 55 ft (SNL/NM 2004b).

Based on the limited streamflow information and piezometer data (well and piezometer locations are shown on Figure 3), streamflow at the Burn Site (sufficient to saturate channel sediments and provide a source of recharge to brecciated fault zones and fracture systems) is sporadic and infrequent. Infiltrating water from these streamflows temporarily saturates alluvial sediments adjacent to the arroyo. Much of the water retained as bank and channel bottom storage most likely returns to the atmosphere through evapotranspiration. If infiltrating water from a flow event or sequence of events is adequate to exceed evapotranspiration losses, water moves downward through the canyon alluvium and is available to enter brecciated fault zones and fractures in underlying bedrock.

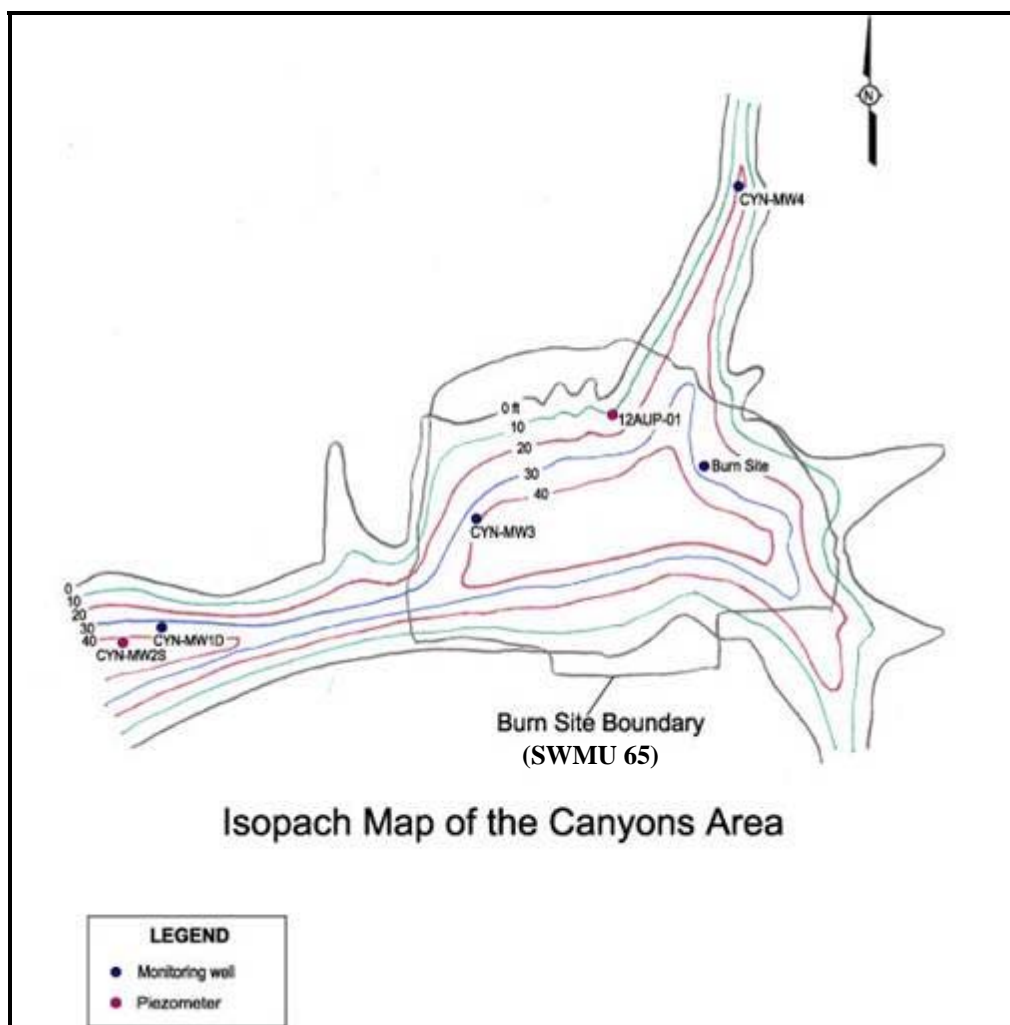
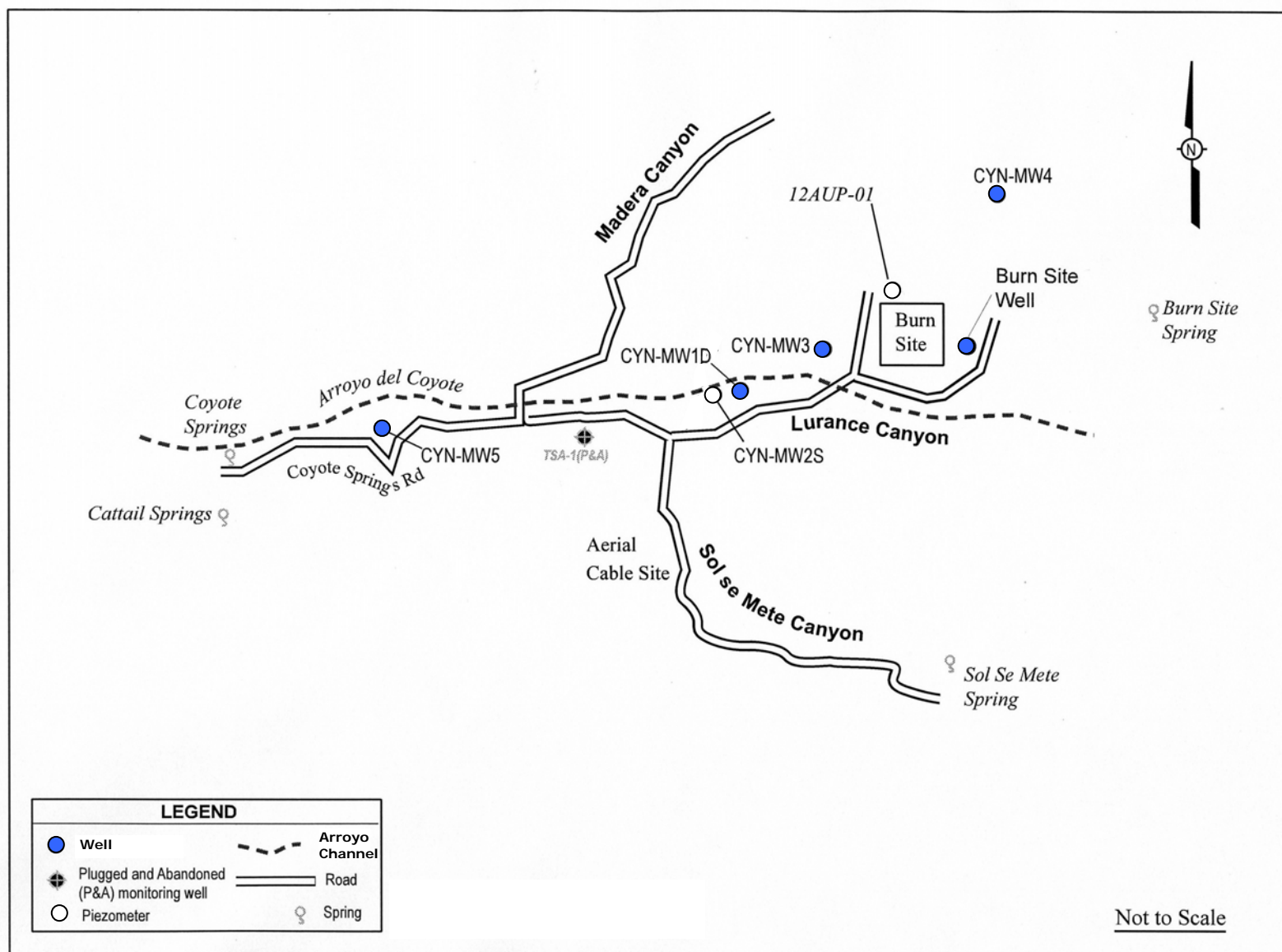


Figure 2. Isopach map of alluvium at the Burn Site.

Nitrate concentrations measured in water from Burn Site wells are attributed to non-point sources either from nitrate disseminated from open detonation of HE from 1967 until the early 1980s or from naturally concentrated nitrate present in rainwater that has been evaporated or transpired from alluvial deposits in Lurance Canyon. Evaluation of nitrate in sediments from nearby pristine alluvial deposits and springs discharging from fractured rocks will be useful in defining the source of nitrate in groundwater at the Burn Site and evaluating whether that source has been depleted. Nitrate concentrations in several wells indicate that a nitrate pulse in groundwater may have moved downgradient across the Burn Site since 1995.

Trace concentrations of HE constituents in BSG are not COCs because concentrations are less than Environmental Protection Agency and state standards. Trace concentrations of HE constituents in groundwater are attributed to the open detonation of HE. These constituents may have been mobilized and concentrated in infiltrating precipitation and runoff, migrating to fault zones and to the water table.



From SNL/NM 2003.

Figure 3. Location of wells, piezometers, and springs at the Burn Site.

## 3.0 RESULTS AND OBSERVATIONS

This section presents observations from sampling and analyses results of alluvium and groundwater. Alluvium sampling and analyses results are presented in the “Field Report Burn Site Groundwater – Nitrate Source Evaluation” (Skelly 2005), and are also included in Appendix A for reference. Alluvium sampling activities and the sampling of the Burn Site Well was conducted under the *Sampling and Analysis Plan - Canyons Area Groundwater - Nitrate Source Evaluation* (Skelly 2004). All other sampling activities were conducted as part of SNL/NM’s Environmental Restoration voluntary monitoring program and data are presented in annual groundwater monitoring reports (SNL/NM 2005b, SNL/NM 2004c). Section 3.1 presents observations from concentration data in alluvium samples and Section 3.2 presents observations on concentration data from water samples. An observation of water in a Burn Site piezometer is recorded in Section 3.3.

### 3.1 Alluvium Sampling Results

Alluvium samples include shallow soil samples collected with a hand auger and deeper samples collected from boreholes. The locations of these samples are shown in Figure 4. Alluvium samples taken outside the Solid Waste Management Unit (SWMU)-65 boundary are considered background samples because there is no evidence of anthropogenic contamination outside of this boundary. Samples taken inside the SWMU 65 boundary represent alluvium that may have been impacted by contaminants released by detonations of HE during historical Burn Site operations.

The shallow alluvium samples were taken at locations outside and near the boundary of SWMU 65. These shallow soil samples were taken at two depths, 0.5 and 2 ft bgs, using a hand auger. Deep borehole locations were both inside (CYN-BH-005 and CYN-BH-006) and outside SWMU 65 (CYN-BH-004). At each location, 2-ft drive samples were collected every 5 ft (starting at 5 ft bgs) until refusal using a hollow stem auger (Skelly 2005).

The soil samples were analyzed for three measures of nitrogen species, including nitrate plus nitrite (NPN), ammonia, and total Kjeldahl nitrogen (TKN) (ammonia and organic nitrogen). All measures of nitrogen species are expressed as nitrogen. It is assumed that NPN is equivalent to nitrate because nitrite is not likely present under aerobic environmental conditions. The soil samples were analyzed for chloride and the shallow alluvium samples were analyzed for HE. Plots showing the concentrations of these constituents with depth are presented in Appendix B.

General observations from alluvium samples collected outside SWMU 65 (background) are:

- **Shallow Soil (SS) samples at CYN-SS-001, CYN-SS-002, and CYN-SS-003.** Nitrate was detected in five of six samples. The maximum concentration detected was 1.25 mg/L in CYN-SS-001 at 2 ft bgs. The maximum detected chloride concentration was 16.5 mg/L, although a duplicate sample at this location was 4.26 mg/L. HE was not detected in any shallow alluvium samples, supporting the assumption that these samples represent background alluvium.

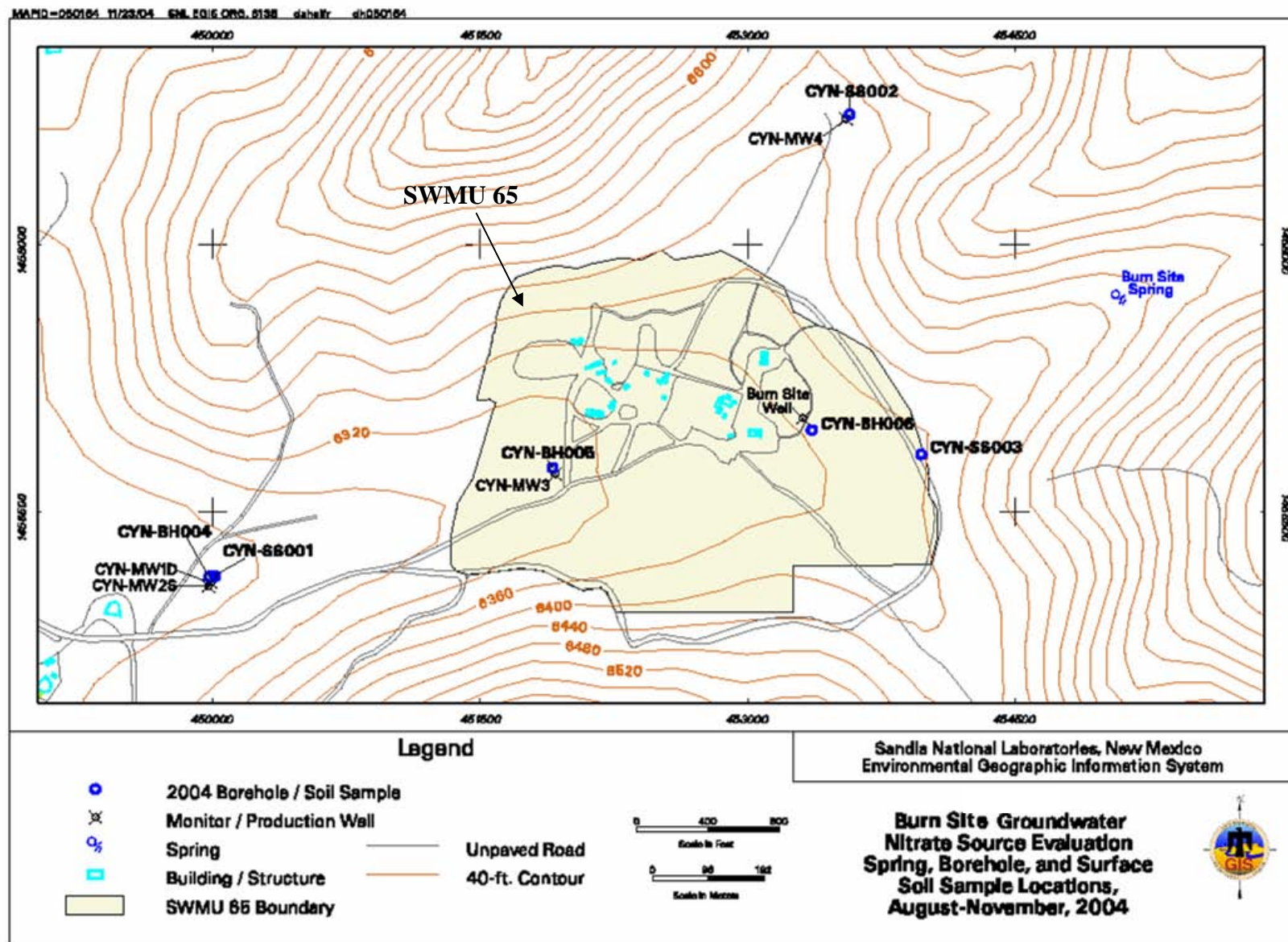


Figure 4. Shallow alluvium, borehole alluvium, and the Burn Site Spring sampling locations (Skelly 2005).

- **CYN-BH-004.** Nitrate concentrations in CYN-BH-004 samples were either estimated values below the detection limit (at 5 ft bgs) or non-detect (10 to 25 ft bgs). The maximum TKN concentration was 115 mg/kg at 5 ft bgs and decreased with depth. Ammonia concentrations were also generally lower than in the shallow alluvium samples (2.00 to 6.84 mg/kg) and chloride concentrations were generally higher (1.75 to 5.23 mg/kg).

General observations from deep alluvium samples collected within the SWMU 65 boundary are:

- **CYN-BH-005.** Nitrate was detected at all depths ranging from 0.75 mg/kg at 25 ft bgs to 4.64 mg/kg at 10 ft bgs. TKN (16 to 302 mg/kg) and ammonia (3.2 to 6.2 mg/kg) were generally lower than the concentrations observed in shallow alluvium samples and tended to decrease with depth. Chloride concentrations at shallower depths (approximately 5 to 15 ft bgs) were much higher than those observed in the shallow samples and in CYN-BH-004 and decreased with depth.
- **CYN-BH-006.** Nitrate was detected at a concentration slightly above the detection limit at 10 ft bgs and at a concentration of 1.63 mg/kg at 15 ft bgs. TKN (191 to 281 mg/kg) and ammonia (4.12 to 6.12 mg/kg) showed similar concentration trends as CYN-BH-005. Chloride concentrations (141 to 161 mg/kg) were also much higher in CYN-BH-006 than in the shallow samples or CYN-BH-004.

### **3.2 Groundwater and Spring Sampling**

Groundwater and spring sampling observations are summarized here to compare concentrations of nitrate in BSG that may have been affected by historical Burn Site operations to background concentrations present in groundwater from locations that are not expected to be affected by these operations. Groundwater sampling locations that may have been affected by Burn Site operations include the Burn Site Well, CYN-MW3, and CYN-MW1D.

Sampling locations that represent background concentrations include the Burn Site Spring, CYN-MW4, CYN-MW5, and Coyote Springs (see Figure 2). CYN-MW4 is a crossgradient well, and the Burn Site Spring represents an upgradient sampling location. Based on potentiometric contour data, flows from Coyote Spring (located approximately 3 miles west of CYN-MW1D) and water from well CYN-MW5 (located approximately 2 miles west of CYN-MW1D) most likely are derived from subregional groundwater flow through the fractured rocks south of the Burn Site (SNL/NM 2004b). Nitrate concentrations in water from these two locations are assumed to represent background.

Appendix A presents a summary of concentrations observed during sampling events at various times since 1996. These concentrations are also plotted in Figure 5. The concentrations are measured as NPN; however, it is assumed that NPN is equivalent to nitrate because nitrite is not likely present under aerobic environmental conditions. As shown in Figure 5, the highest observed nitrate concentration at a background location is 2.55 mg/L at CYN-MW5, and nitrate concentrations in these wells are relatively stable with no increasing or decreasing trend.



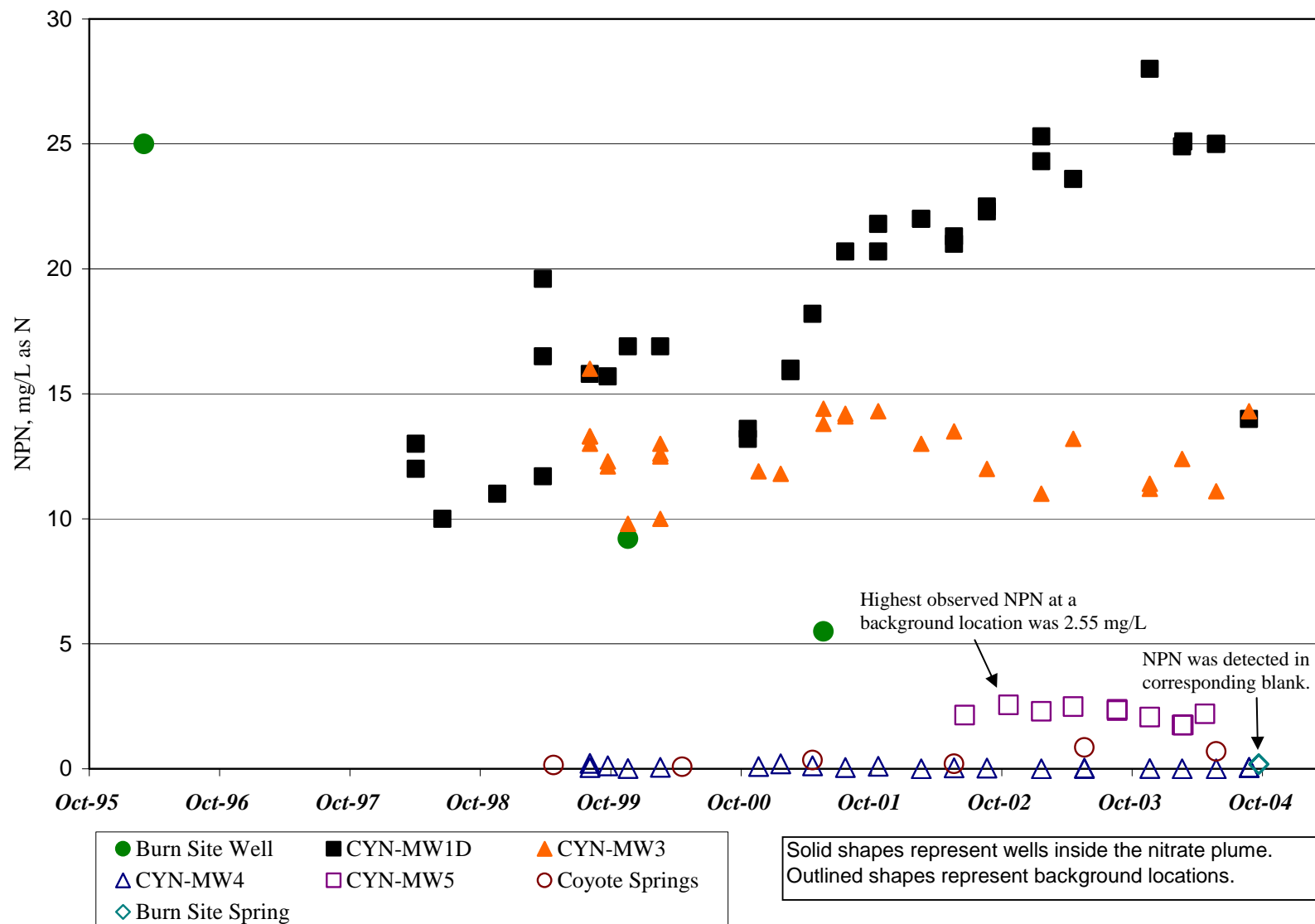


Figure 5. Nitrate concentrations over time in water from selected wells and springs.

Elevated nitrate concentrations have been observed in three wells (the Burn Site Well, CYN-MW3, and CYN-MW1D). Nitrate concentrations in samples from the Burn Site Well have declined from 25 mg/L in 1996 to 5.5 mg/L in 2001. Nitrate concentrations in well CYN-MW3 have remained relatively stable in the 10 to 15 mg/L range. In well CYN-MW1D, the furthest downgradient well within the elevated nitrate plume, nitrate concentrations have increased from 10 mg/L in 1998 to 25 mg/L in 2004, indicating that a pulse of nitrate has migrated from the Burn Site Well area downgradient to well CYN-MW1D. This pulse was not observed in well CYN-MW3. A possible explanation for this is that the hydraulic connection between well CYN-MW3 and the main nitrate flow path is limited and/or intermittent.

### **3.3 *Observed Flow in the Vadose Zone***

Piezometer 12AUP-01 was installed in 1996 to evaluate the potential for shallow groundwater flow in the channel alluvium. No water was detected in this piezometer until September 2, 2004. After a series of significant rain events, between 1 and 2 inches of water was measured in the piezometer. The water level remained fairly constant through September. However, more recent water level measurements show no measurable water in 12AUP-01. It is likely that significant moisture is present in the vadose zone only after a series of significant rain events. Episodic accumulation of precipitation may provide a mechanism for recharge through brecciated fault zones and fractures in the underlying bedrock.



## 4.0 DISCUSSION

This section addresses the two objectives of the source evaluation, which are:

1. Compare the background nitrate concentrations in alluvium and groundwater to the nitrate concentrations within the Burn Site and within the BSG nitrate plume (Section 4.1), and
2. Evaluate the potential for a continuing source of nitrate in the vadose zone (Section 4.2).

### 4.1 *Background Nitrate*

Background nitrate concentrations were obtained from the analysis of water and alluvium samples for consideration during future groundwater monitoring and to provide some indication of the relative contribution of potential sources. The source of nitrate contamination in BSG is uncertain. The two most probable sources of nitrate in BSG are:

1. Accumulation of naturally-occurring nitrate in the vadose zone by evapotranspiration, and
2. Dissemination of nitrate during historical Burn Site operations followed by leaching into soil and groundwater (SNL/NM 2004b).

The concentration data indicate that nitrate in the alluvium and groundwater originates from both sources but that the higher concentrations of nitrate are emanating from the area of SWMU 65. Key observations that support this conclusion are:

- Nitrate was detected in alluvium samples collected from inside and outside of the SWMU-65 boundary, but the highest nitrate concentrations were detected within SWMU 65 (CYN-BH-005).
- The highest nitrate concentrations in groundwater were detected in samples collected from the Burn Site Well, CYN-MW-3, and CYN-MW1D. Nitrate has been detected in a crossgradient well (CYN-MW4), a downgradient-sentry well (CYN-MW5), an upgradient spring (Burn Site Spring), and a distant downgradient spring (Coyote Spring) but at significantly lower concentrations and are interpreted to represent background conditions.
- Nitrate concentration trends in two wells (Burn Site Well and CYN-MW1D) indicate that a nitrate pulse in groundwater may have moved downgradient across the Burn Site since 1995.

Based on these observations, nitrate in the alluvium at the Burn Site most likely is derived both from natural accumulation and from HE. Based on comparison of the nitrate data from inside and outside of the SWMU 65 boundary, background concentrations in groundwater likely range from non-detect to less than 4 mg/L, which is the level approved by NMED to represent background nitrate concentrations (NMED 1997).

## **4.2 *Potential for a Continuing Nitrate Source in the Vadose Zone***

An important consideration when evaluating remedial alternatives is the nature of the nitrate source term. A determination that there is no active source term is part of the tiered approach to evaluating the monitored natural attenuation remedial alternative identified in the Remedial Alternatives Data Gaps Review (SNL/NM 2005a). Evaluation of nitrate concentrations in the vadose zone alluvium suggests that this nitrate is not a significant active source term to groundwater.

According to the Current Conceptual Model of Contaminant Transport at the Burn Site (SNL/NM 2004b), nitrate moved into groundwater during recharge events. Assuming that nitrate in the alluvium around CYN-BH-005 originated from the pre-1980 detonation of explosives (SNL/NM 2004b), those conditions in which recharge to the groundwater may have occurred (as was observed in piezometer 12AUP-01 after a series of significant rainfall events) have not moved this mass of nitrate into groundwater. This suggests that residual nitrate in soil at some locations may not be readily leached into groundwater during significant precipitation events.

An estimate of the impacts to groundwater that could result from future leaching of nitrate in the soil within the SWMU-65 boundary is presented in Appendix C. This analysis assumed several conservative parameters (i.e., the worst-case). The analysis showed that the maximum concentration of nitrate in pore water that could reach the underlying groundwater was between 12 and 37 mg/L (depending on the assumed porosity of alluvial materials). This does not represent a significant increase above the observed maximum groundwater nitrate concentration of 28 mg/L.

## 5.0 CONCLUSIONS

The primary conclusions of the nitrate source evaluation are:

- Nitrate in alluvium and groundwater at the Burn Site is a result of both natural phenomenon and historical Burn Site operations.
- Elevated nitrate concentrations in soil near the Burn Site and in a groundwater plume emanating from the Burn Site are likely the result of historical Burn Site operations, followed by leaching of nitrate into the subsurface.
- Nitrate remains in the alluvium at the Burn Site, which is in the vadose zone; however, this nitrate does not represent an active source that would significantly increase nitrate concentrations in groundwater. A conservative estimate indicates that the nitrate remaining in the vadose zone is unlikely to result in groundwater contamination at concentrations higher than have been observed in the past.

## 6.0 REFERENCES

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**Appendix A**  
**Tabulated Alluvium, Spring Water, and Groundwater**  
**Analytical Data**

Table A-1. Analytical Results for Soil Samples BSG Study Area Nitrate Source Evaluation (Skelly 2005).

Sample Number	Sample ID	End Depth (ft bgs)	NPN (mg/kg)	TKN (mg/kg)	Ammonia (mg/kg)	Cl (mg/kg)	HE (µg/kg)
<b>Shallow Soil Samples</b>							
066225	SWC-CYN-Nitrate-SS-01-000.5	0.5	0.347	633	12.5	1.17J	ND (125)
066226	SWC-CYN-Nitrate-SS-01-002	2	1.25	1350	14.5	2.13	ND (125)
066227	SWC-CYN-Nitrate-SS-02-000.5	0.5	0.376	1320	17.4	ND (0.316)	ND (125)
066228	SWC-CYN-Nitrate-SS-02-002	2	0.190J	818	11.7	ND (0.322)	ND (125)
066229	SWC-CYN-Nitrate-SS-03-000.5	0.5	1.02	2110	39.8	ND (0.322)	ND (125)
066230	SWC-CYN-Nitrate-SS-03-002	2	ND (0.070) R	748	13.3	4.26	ND (125)
066232	SWC-CYN-Nitrate-SS-03-002	2 (DUP)	ND (0.070) R	861	12.5	16.5	ND (125)
<b>Deep Borehole Samples</b>							
066233	SWC-CYN-BH-004-005	5	0.109J	115	2.56	5.23	--
066234	SWC-CYN-BH-004-010	10	ND (0.070) R	62.3	2.88	1.75	--
066236	SWC-CYN-BH-004-015	15	ND (0.070) R	30.4	2.08	3.99	--
066237	SWC-CYN-BH-004-020	20	ND (0.070) R	5.44	2.00	3.78	--
066238	SWC-CYN-BH-004-025	25	ND (0.070) R	10.1	6.84	4.65	--
066242	SWC-CYN-BH-005-005	5	2.79	305	6.08	151	--
066243	SWC-CYN-BH-005-005	5 (DUP)	2.72	299	6.00	143	--
066244	SWC-CYN-BH-005-010	10	4.64	286	6.20	67.6	--
066245	SWC-CYN-BH-005-015	15	4.16	64.2	4.48	20.3	--
066246	SWC-CYN-BH-005-020	20	4.57	112	4.34	13.7	--

Table A-1 (continued).

Sample Number	Sample ID	End Depth (ft bgs)	NPN (mg/kg)	TKN (mg/kg)	Ammonia (mg/kg)	Cl (mg/kg)	HE (µg/kg)
<b>Deep Borehole Samples (continued)</b>							
066247	SWC-CYN-BH-005-025	25	0.755	52.2	3.76	16.6	--
066248	SWC-CYN-BH-005-030	30	0.777	26.0	3.26	8.40	--
066249	SWC-CYN-BH-005-035	35	2.05	15.5	3.24	5.60	--
066251	SWC-CYN-BH-006-005	5	ND (0.070) R	281	6.12	161	--
066252	SWC-CYN-BH-006-010	10	0.195J	207	7.08	143	--
066254	SWC-CYN-BH-006-010	10 (DUP)	0.174J	195	5.06	138	--
066255	SWC-CYN-BH-006-015	15	1.63	191	4.12	143	--
<b>Equipment Blanks (mg/L)</b>							
066231	SWC-CYN-Nitrate-SS-EB	NA	0.0179J	0.162	ND (0.0159)	ND (0.0322)	ND (0.162–0.487)
066261	SWC-CYN-BH-004-EB	NA	0.059	--	--	ND (0.0322)	--

**Analytical methods:**

NPN = EPA 353.1 Nitrogen, Nitrate/Nitrite.  
 TKN = PA 351.2 Nitrogen, Total Kjeldahl.  
 Ammonia = PA 350.1 Nitrogen, Ammonia.  
 Cl = W846 9056 Chloride in soil.

**Notes:**

bgs = Below ground surface.	mg/L = Milligrams per liter.
BH = Borehole.	NA = Not applicable.
Cl = Chloride	ND = Not detected (with detection limits).
CYN = Canyons.	NPN = Nitrate plus nitrite.
DUP = Duplicate.	R = Data rejected during Data Validation; QC failures associated with the samples that are due in part to the non-homogeneous nature of the samples and in part to the sample matrix.
EPA = Environmental Protection Agency	SS = Surface soil.
ft = Feet.	SWC = Site Wide Characterization.
HE = High explosives.	TKN = Total Kjeldahl Nitrogen.
ID = Identification.	ug/kg = Micrograms per kilogram.
J = Estimated value below detection limit.	-- = Not analyzed.
mg/kg = Milligrams per kilogram.	

Table A-2. Nitrate Groundwater Monitoring Data.

Date	Type	CYN-MW1D (mg/L)	CYN-MW3 (mg/L)	CYN-MW4 (mg/L)	CYN-MW5 (mg/L)	Burn Site Well (mg/L)	Coyote Springs (mg/L)	Burn Site Spring (mg/L)
Mar-96	primary					25 B		
Apr-98	primary	12						
Apr-98	duplicate	13						
Jun-98	primary	10						
Dec-98	split	11						
Apr-99	primary	11.7						
Apr-99	duplicate	16.5						
Apr-99	triplicate	19.6						
Apr-99	split	13.9						
May-99	primary						0.15 B, J	
Aug-99	primary	15.8	13.3	0.22				
Aug-99	split		17	0.4				
Aug-99	micropurge		13.3	0.05				
Aug-99	micropurge		18	0.2				
Aug-99	micropurge		13					
Oct-99	primary	15.8	12.1	0.12				
Oct-99	split	22	3.3	0.3				
Oct-99	duplicate		12.3					
Dec-99	primary	16.9	9.8	0.01		9.2		
Dec-99	duplicate		17					
Dec-99	split	23		0.2				
Mar-00	primary	16.9	13	0.06				
Mar-00	duplicate		10					
Mar-00	split	20	11	0.65				
May-00	primary		12.5				0.08	



Table A-2. (continued).

Date	Type	CYN-MW1D (mg/L)	CYN-MW3 (mg/L)	CYN-MW4 (mg/L)	CYN-MW5 (mg/L)	Burn Site Well (mg/L)	Coyote Springs (mg/L)	Burn Site Spring (mg/L)
May-00	duplicate		12.6					
Nov-00	primary	13.2						
Nov-00	duplicate	13.6						
Dec-00	primary		11.9	0.09 B, J				
Feb-01	primary		11.8	0.2 J				
Feb-01	primary			0.4 J				
Mar-01	primary	16						
Mar-01	duplicate	15.9						
Mar-01	split	27						
May-01	primary	18.2		0.12			0.35	
Jun-01	primary		14.4			5.5		
Jun-01	duplicate		13.8					
Jun-01	split					8.3		
Aug-01	primary	20.7	14.2 B	0.05				
Aug-01	duplicate		14.1 B					
Nov-01	primary	20.7	14.3	0.1				
Nov-01	duplicate	21.8						
Mar-02	primary	22	13	U				
Mar-02	duplicate	22						
Mar-02	split		12.5					
Jun-02	primary	21.3	13.5	0.04 J			0.2	
Jun-02	duplicate	21						
Jul-02	primary				2.15			
Sep-02	primary	22.5	12	0.03 B, J				
Sep-02	duplicate	22.3						
Nov-02	primary				2.55			

<b>Date</b>	<b>Type</b>	<b>CYN-MW1D (mg/L)</b>	<b>CYN-MW3 (mg/L)</b>	<b>CYN-MW4 (mg/L)</b>	<b>CYN-MW5 (mg/L)</b>	<b>Burn Site Well (mg/L)</b>	<b>Coyote Springs (mg/L)</b>	<b>Burn Site Spring (mg/L)</b>
Feb-03	primary	24.3	11 B	U	2.3 B			
Feb-03	duplicate	25.3 B						
May-03	primary	23.6	13.2		2.49			
Jun-03	primary			0.03 J			0.85	
Jun-03	duplicate			0.01 J				
Sep-03	primary				2.33			
Sep-03	duplicate				2.38			
Dec-03	primary	28.0	11.2	0.010	2.07			
Dec-03	duplicate		11.4					
Mar-04	primary	24.9	12.4	U	1.75			
Mar-04	duplicate	25.1			1.75			
May-04	primary				2.20			
Jun-04	primary	25.0	11.1	U			0.70	
Jun-04	duplicate	25.0						
Sep-04	primary	14.0	14.3	0.0473				
Sep-04	duplicate			0.0474				
Oct-04	primary							0.211 B
Oct-04	duplicate							0.171 B
Oct-04	triplicate							0.168 B

B = Analyte was also present in quality-control blank samples.

J = Estimated quantity: analyte was detected below the reporting limit.

U = Analyte was detected below the detection limit.

## **Appendix B**

### **Plots of Constituent Concentration in Soil with Depth**

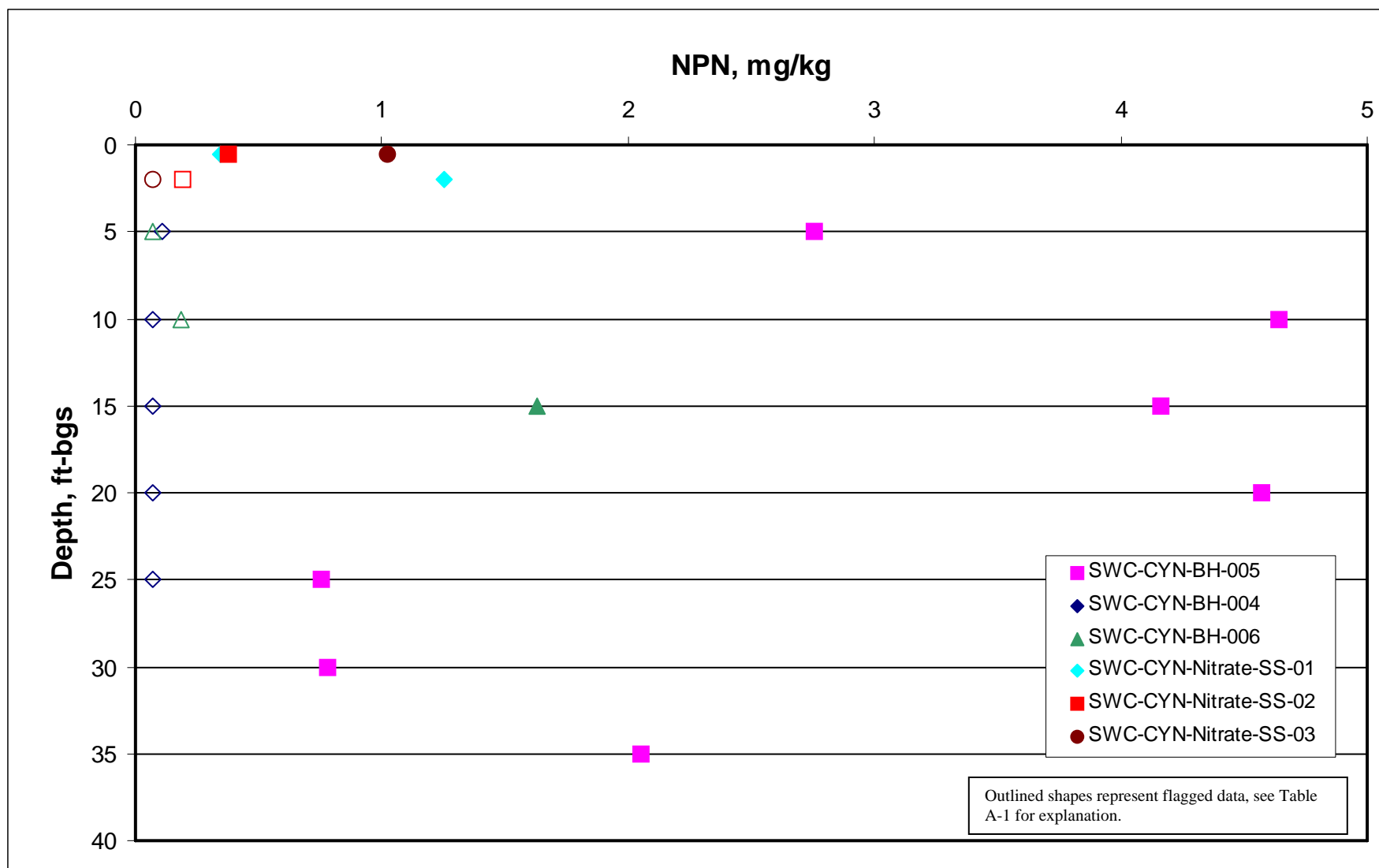


Figure B-1. Nitrate concentrations in Burn Site soil samples (October 2004).

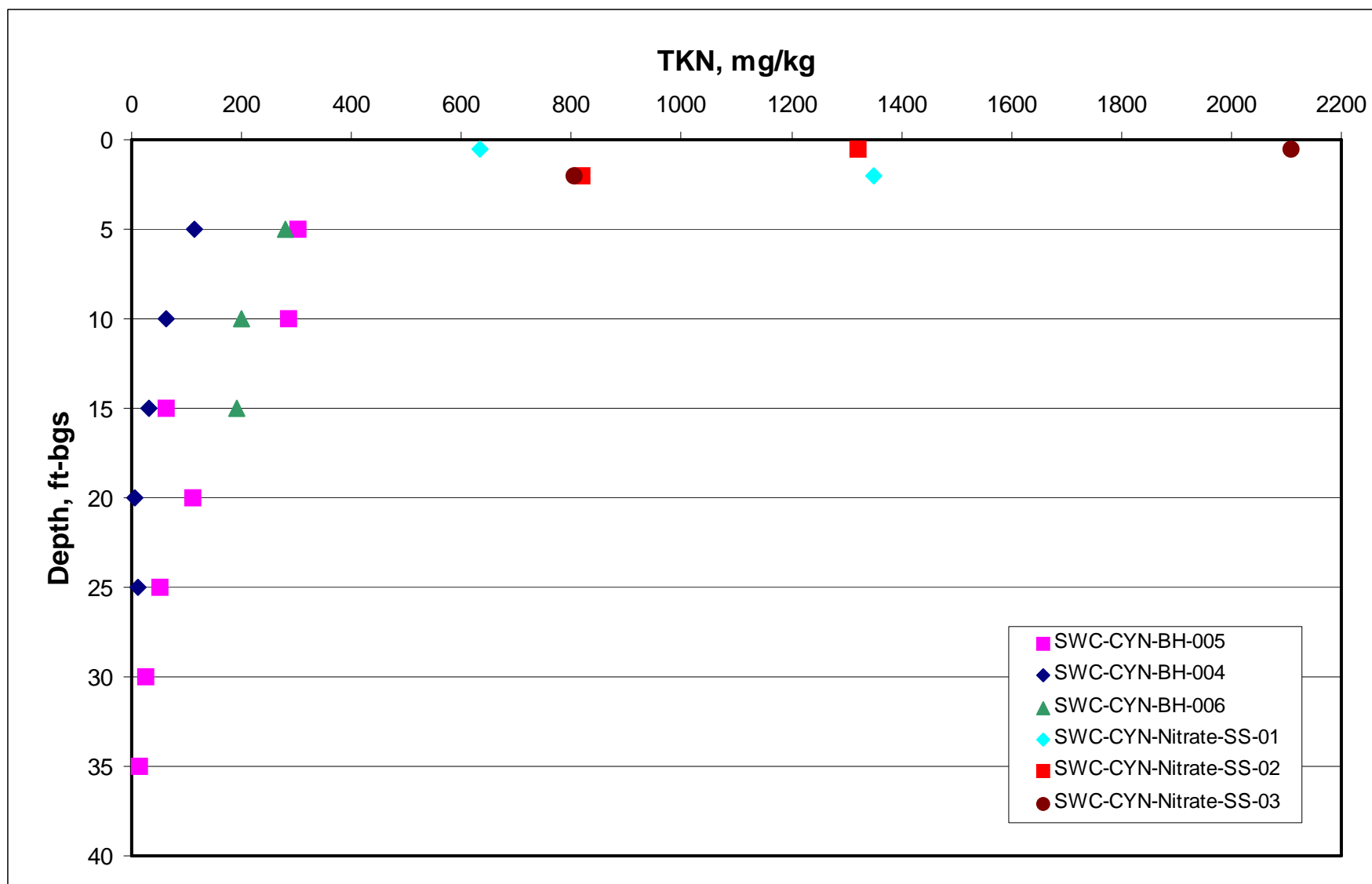


Figure B-2. TKN concentrations in Burn Site soil samples (October 2004).

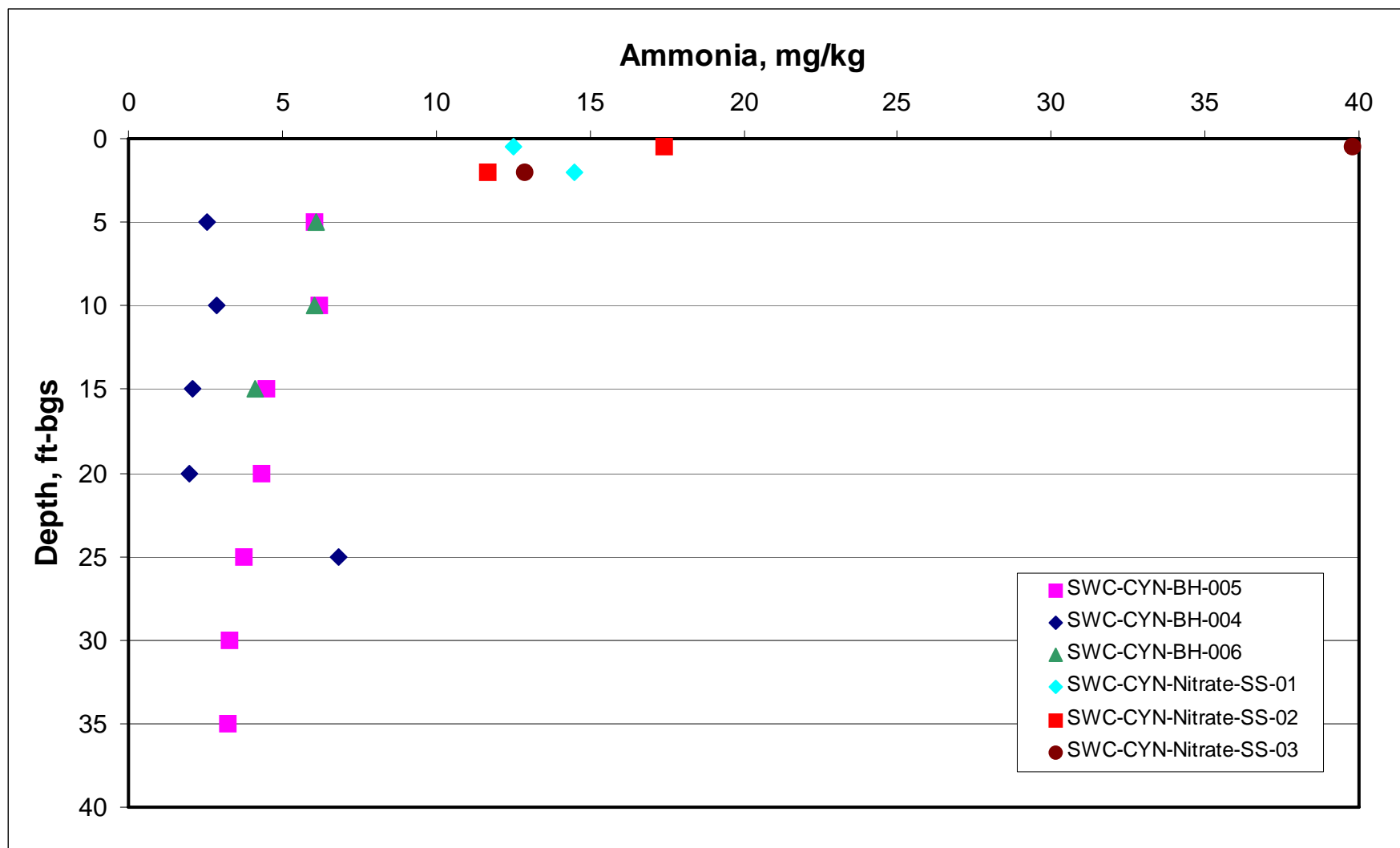


Figure B-3. Ammonia concentrations in Burn Site soil samples (October 2004).

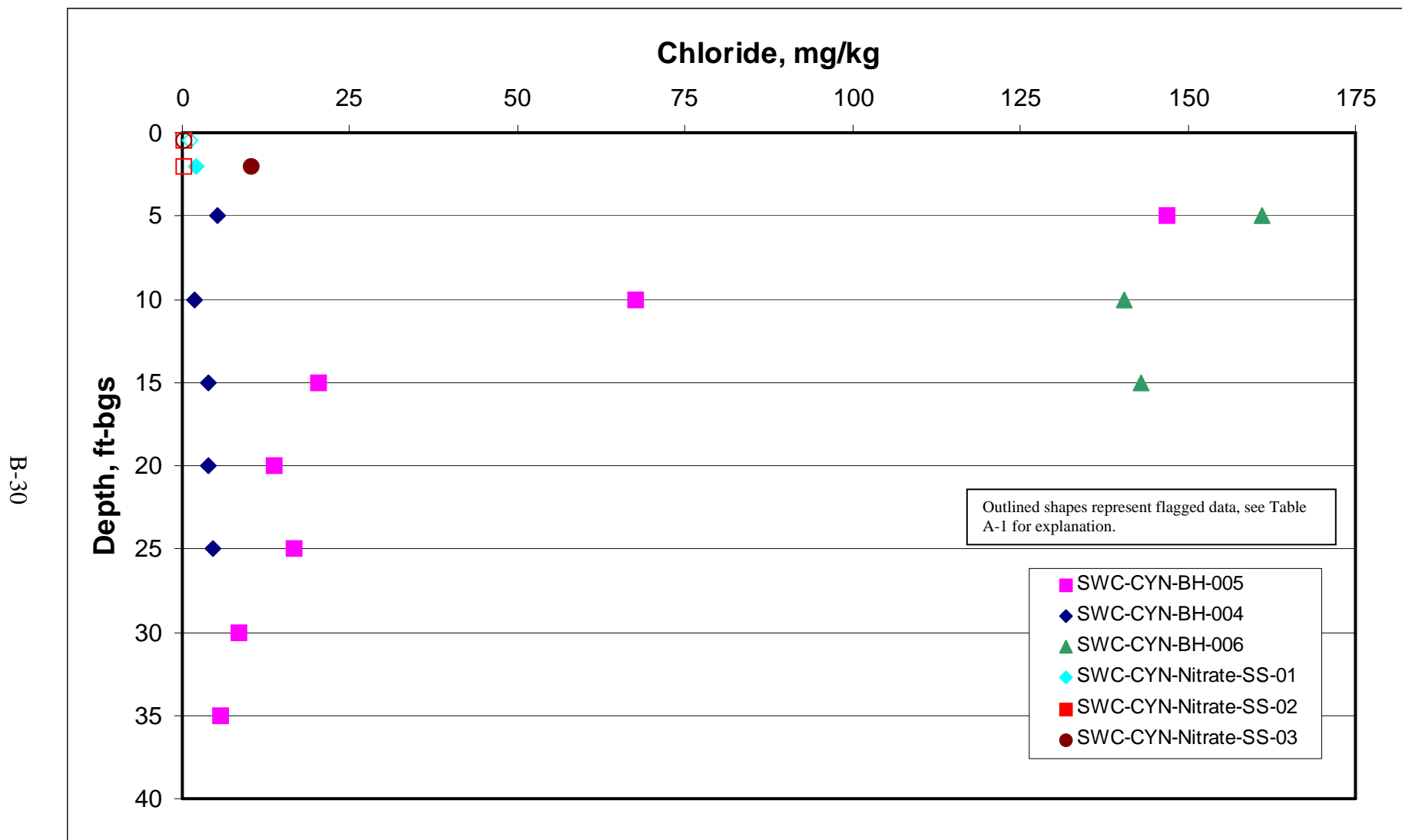


Figure B-4. Chloride concentrations in Burn Site soil samples (October 2004).

## **Appendix C**

### **Estimation of Potential Nitrate Leaching**



## C-1. Estimation of Potential Nitrate Leaching

Elevated nitrate concentrations in alluvial soil samples collected from the vadose zone within SWMU 65 are a potential source of additional nitrate contamination to groundwater. This appendix presents a conservative estimate of possible nitrate groundwater concentration increases due to the potential migration of nitrate through the vadose zone into groundwater. This estimate is based on the following assumptions:

- The highest detected concentration of nitrate in the alluvium (4.64 mg/kg, observed at 10 ft bgs in CYN-BH-005) represents the nitrate concentration in the vadose zone alluvium.
- The alluvium is saturated during a precipitation event. Following saturation, this water flows downward and recharges the aquifer. No water is lost through evaporation. It is recognized that this assumption is unlikely given the dry climate and the persistence of nitrate in the vadose zone 24 years after detonations of HE have ceased. However, the assumption is made here to estimate an upper bound of nitrate concentration in water that could recharge local groundwater.
- Upon saturation of the alluvium, the entire mass of nitrate in the alluvium is dissolved instantaneously into a single pore volume of water, and the nitrate-contaminated water recharges the groundwater.
- There is no dilution of nitrate during transport from the vadose zone into the groundwater. This assumption will also tend to unrealistically conserve the higher nitrate concentration given the path of groundwater recharge, which may occur through faults and into bedrock with potential for dilution or dispersion of nitrate during this migration.
- The porosity ( $\eta$ ) of the alluvial material ranges from 25 to 50% based on a range of literature values for soil materials (Freeze and Cherry 1979).
- The granular density of the material is 2.66 g/cm<sup>3</sup> based on literature values for quartz materials (Sowers and Sowers 1970).

The concentration of nitrate in the pore water (upon saturation of the alluvium and dissolution of the nitrate) is represented by Equation 1. This equation was derived based on the assumptions stated and the relationship between granular density, porosity, and a mass per mass (dry weight) concentration of nitrate in soils.

$$C_{porewater} = \frac{(1 - \eta)\rho C_{drysoil}}{\eta} \quad (1)$$

where:

$C_{\text{porewater}}$  = dissolved concentration ( $\text{g/m}^3$ ),

$C_{\text{drysoil}}$  = concentration in soil ( $\text{g/g}$ ),

$\eta$  = porosity of the alluvium, and

$\rho$  = granular density ( $\text{g/m}^3$ ).

The calculated concentration of nitrate in the pore water that could reach groundwater ranges from 12 to 37 mg/L, depending on the value of porosity used. If pore water carrying this nitrate recharges groundwater without dilution or dispersion, then an upper bound on the nitrate concentration would be approximately 12 to 37 mg/L, depending on the actual porosity of the alluvium. This estimate represents a conservative upper bound because other factors, such as dilution of nitrate contaminated pore water from the vadose zone with groundwater, would decrease concentrations.

**Attachment C**

**Evaluation of Contaminant Transport for  
Burn Site Groundwater**

# **Evaluation of Contaminant Transport for Burn Site Groundwater at Sandia National Laboratories/New Mexico**

**March 2005**

Prepared by  
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## EXECUTIVE SUMMARY

The *Corrective Measures Evaluation Work Plan Burn Site Groundwater* outlines a staged process for evaluating remedial alternatives at the Burn Site at Sandia National Laboratories/New Mexico. The numerical modeling study described herein was performed as part of the Corrective Measures Evaluation to determine the effects of dilution on nitrate in Burn Site groundwater as it is transported downgradient. Nitrate is present in the Burn Site groundwater at concentrations exceeding the federal maximum contaminant level (10 mg/L as nitrogen).

A simplified cross-sectional analysis was used to assess downgradient nitrate transport. The analysis divided groundwater flow into four sections: (1) Lurance Canyon model section, (2) transition section, (3) alluvial fan lithofacies model section, and (4) Ancestral Rio Grande lithofacies model section. Nitrate concentrations were estimated for two potential receptors: (1) ecological receptors at Coyote Springs in Lurance Canyon, and (2) human receptors at municipal pumping centers near Albuquerque, New Mexico.

The flow models were used to make conservative simulations of the effects of dilution on elevated nitrate concentrations during migration from the Burn Site area to potential downgradient receptor locations at springs and pumping centers. Recognizing that the cross-sectional numerical flow and transport models would not be a rigorous representation of the system, several conservative assumptions were made so that the effects of dilution would be intentionally underestimated.

Simulated nitrate concentrations were reduced to approximately 28% before reaching the nearest potential downgradient receptor location at Coyote Springs. The simulated maximum concentration at the springs occurs after approximately 290 years of transport. This estimate of relative concentration reduction suggests that the contaminants in Burn Site groundwater will be diluted to below the Environmental Protection Agency drinking water maximum contaminant level of 10 mg/L before reaching the potential ecological receptors at the springs.

Simulated nitrate concentrations were reduced to 0.2% of the initial maximum concentration as the solute plume moved into the more permeable alluvial fan section, and were reduced again to 0.003% of the initial concentration as the plume moved into the even more permeable ancestral Rio Grande section. The simulation indicates that nitrate originating from the Burn Site will be reduced to at least 0.003% of the current maximum nitrate concentration before reaching pumping centers, located in the ancestral Rio Grande deposits, in more than 660 years.

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## ACRONYMS AND ABBREVIATIONS

ARG	ancestral Rio Grande
CME	Corrective Measures Evaluation
COA	City of Albuquerque
ft	foot or feet
ft/day	feet per day
ft <sup>3</sup> /day	cubic feet per day
ft/yr	feet per year
GMS	Department of Defense Groundwater Modeling System
HE	high explosives
KAFB	Kirtland Air Force Base
LAARC	Light Air Transport Accident Resistant Container
MCL	maximum contaminant level
mg/L	milligrams per liter
NMED	New Mexico Environmental Department
SNL/NM	Sandia National Laboratories/ New Mexico
USGS	United States Geological Survey



## 1.0 INTRODUCTION

This report presents the approach and results of a numerical modeling study performed to evaluate dilution of nitrate during transport to the locations of potential receptors of nitrate-contaminated groundwater originating from the Burn Site at Sandia National Laboratories/New Mexico (SNL/NM). Nitrate is present in the Burn Site groundwater at concentrations exceeding the federal maximum contaminant level (MCL) (10 mg/L as nitrogen).

The *Corrective Measures Evaluation Work Plan Burn Site Groundwater* (SNL/NM 2004a) was prepared as directed by the Compliance Order on Consent issued by the New Mexico Environment Department (NMED) (NMED 2004). The Corrective Measures Evaluation (CME) Work Plan outlines a staged process for evaluating remedial alternatives. This numerical modeling study has been performed as part of the CME process.

A conceptual model for the Burn Site is also required as part of the CME process. This conceptual model is presented in the *Current Conceptual Model of Groundwater Flow and Contaminant Transport at Sandia National Laboratories/New Mexico Burn Site* (SNL/NM 2004b). Section 2 presents a summary of this conceptual model, which provides the basis for the evaluation of contaminant transport and dilution.

The *Remedial Alternatives Data Gaps Review for Burn Site Groundwater* (SNL/NM 2005a) was prepared as part of the paper study stage. During the paper study stage, data gaps in the CME were identified. These data gaps included evaluating the potential for contaminants originating from the Burn Site to reach potential ecological and human receptors, and evaluating the effects of natural attenuation mechanisms on contaminant concentrations. Identification of these and other data gaps resulted in the revised CME process illustrated in Figure 1-1.

The evaluation of nitrate transport and dilution described in this document is the numerical modeling step of the CME process. This report presents the methods and assumptions made for the numerical modeling evaluation (Section 3.0), the results of the evaluation (Section 4.0), and conclusions (Section 5.0).

### 1.1 Purpose and Scope

This report describes a numerical modeling study performed to evaluate reduction in concentrations along the groundwater flow path between the current location of contaminants near the Burn Site and potential downgradient receptors. Activities consisted of developing simplified two-dimensional, steady-state, cross-sectional numerical flow models. These numerical models were used to address dilution, which is one of the abiotic processes that contribute to reduction of contaminant concentrations resulting from transport through the aquifer.

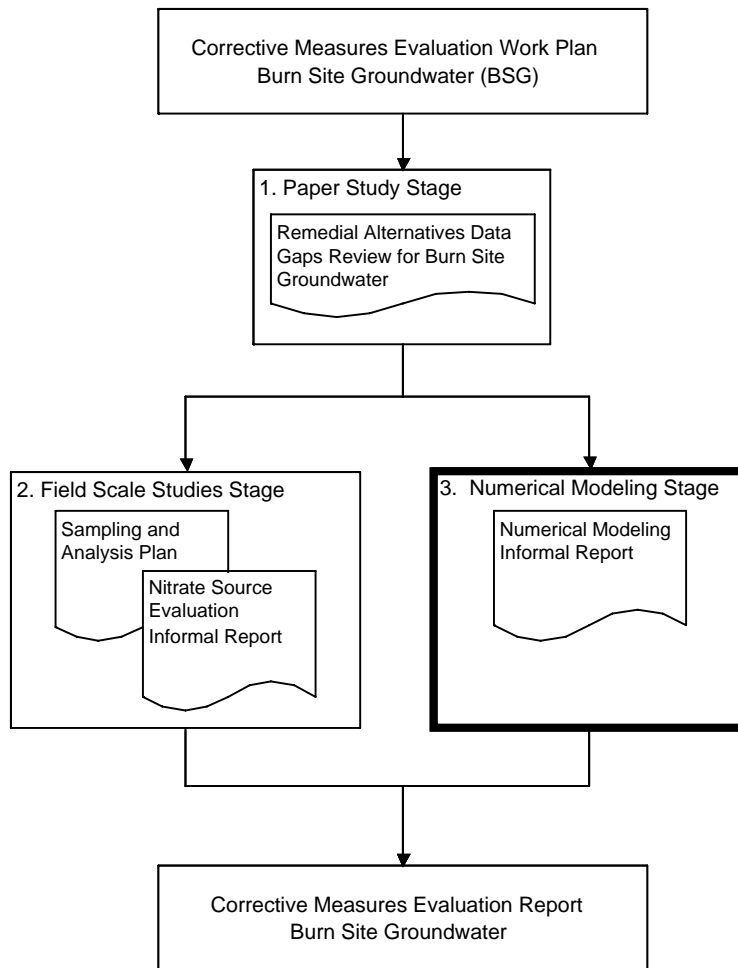


Figure 1-1. Illustration of the staged process of data gathering activities and production of subsequent reports.

## 1.2 Site Background

Sandia National Laboratories/New Mexico (SNL/NM) is located on Kirtland Air Force Base (KAFB) south of Albuquerque, New Mexico (Figure 1-2). SNL/NM manages the Canyons Test Area (Operable Unit 1333), which consists of three large canyons in the Manzanita Mountains (Madera Canyon from the north, Sol se Mete Canyon from the south, and Lurance Canyon from the east) (see Figures 1-2 and 1-3). These canyons channel the headwaters of Arroyo del Coyote. The Burn Site, located in Lurance Canyon, is a test site in the Canyons Test Area.

The Burn Site has been used since 1967 to test the effects of impact, burning, and explosive detonation on equipment components. Historical operations included open detonation of high explosives (HE). Most HE testing occurred between 1967 and 1975 and was completely phased out by the 1980s. Groundwater at the Burn Site contains nitrate at levels exceeding the natural background. In 2004, the NMED identified the Burn Site as an area with groundwater contamination requiring completion of a CME (NMED 2004).

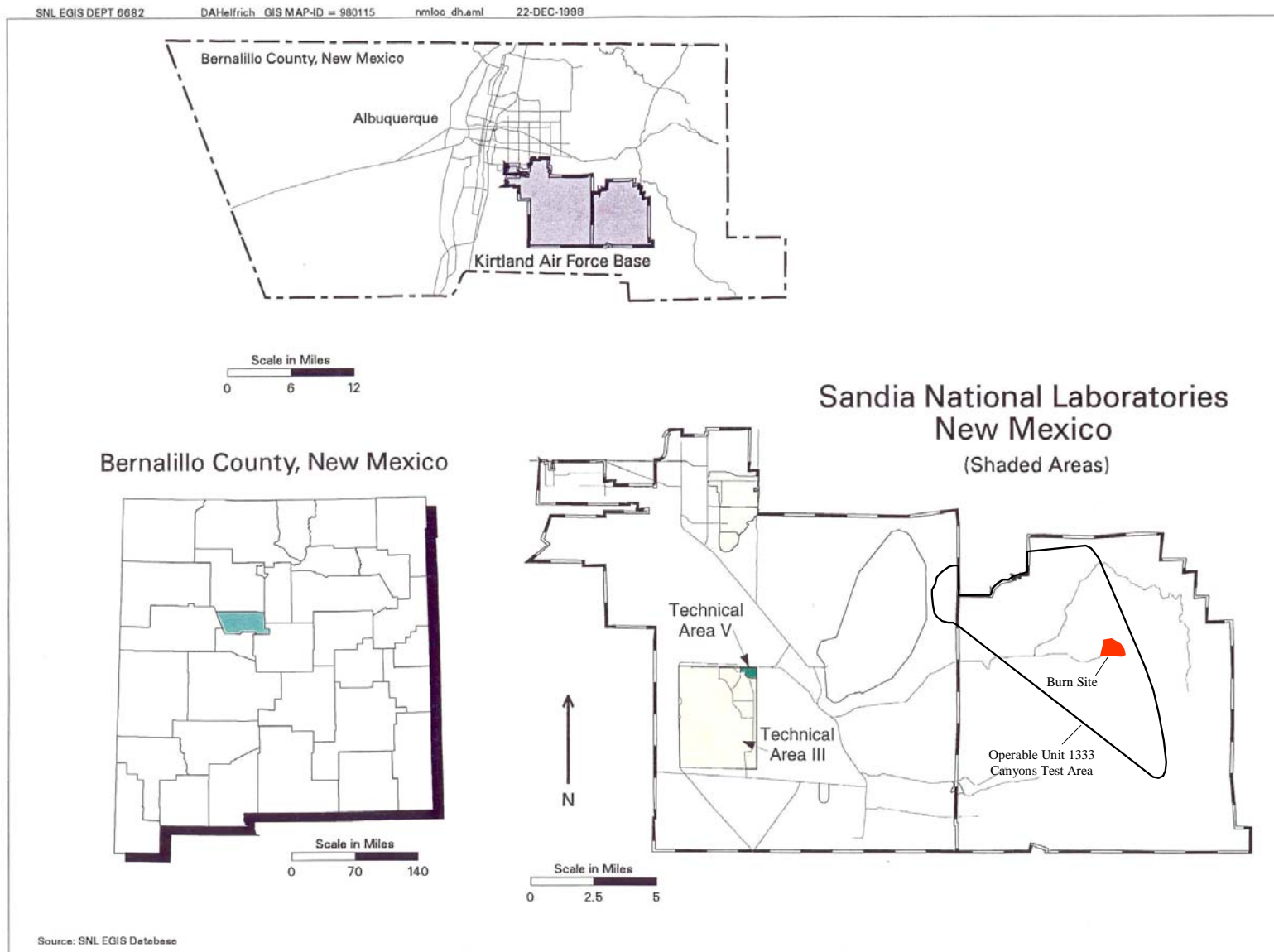


Figure 1-2. Location of the Burn Site, other SNL/NM facilities, and KAFB.

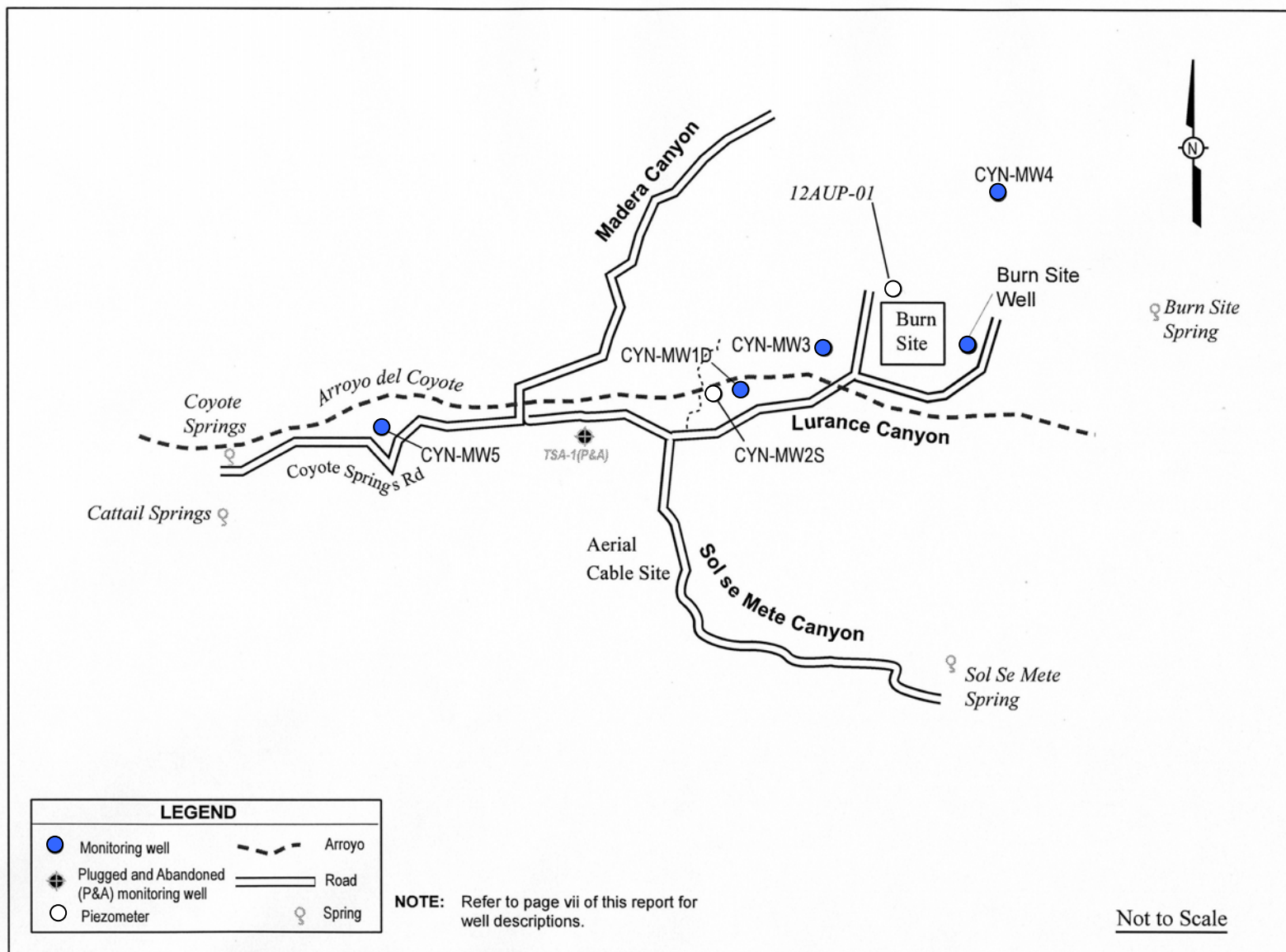


Figure 1-3. Location of wells, piezometers, and springs at the Burn Site.

## 2.0 CONCEPTUAL MODEL

This section summarizes hydrogeologic characteristics of the Burn Site and the surrounding region that provide the basis for the numerical modeling approach used. This section presents a summary of the Current Conceptual Model for Burn Site Groundwater (SNL/NM 2004b). Information from the *Current Conceptual Model of Groundwater Flow and Contaminant Transport at Sandia National Laboratories/New Mexico Technical Area V* (SNL/NM 2004c) is also summarized as a conceptual model for the Albuquerque Basin.

Groundwater at the Burn Site, located in Lurance Canyon, flows westward through crystalline and sedimentary rocks, entering the Albuquerque Basin as underflow. This underflow moves westward and then northward within basin-fill deposits towards well fields in Albuquerque. The hydrogeologic conceptual model of Lurance Canyon is described in Section 2.1, and the conceptual model of the Albuquerque Basin is discussed in Section 2.2.

### 2.1 Lurance Canyon

The Burn Site is located in Lurance Canyon within the Manzanita Mountains east of the Albuquerque Basin of the Rio Grande Rift in north-central New Mexico. The geologic and hydrologic conditions of the Manzanita Mountains form the regional context for groundwater flow and contaminant migration in Lurance Canyon (Section 2.1.1). Local characteristics of groundwater flow and contaminant transport are discussed in Section 2.1.2.

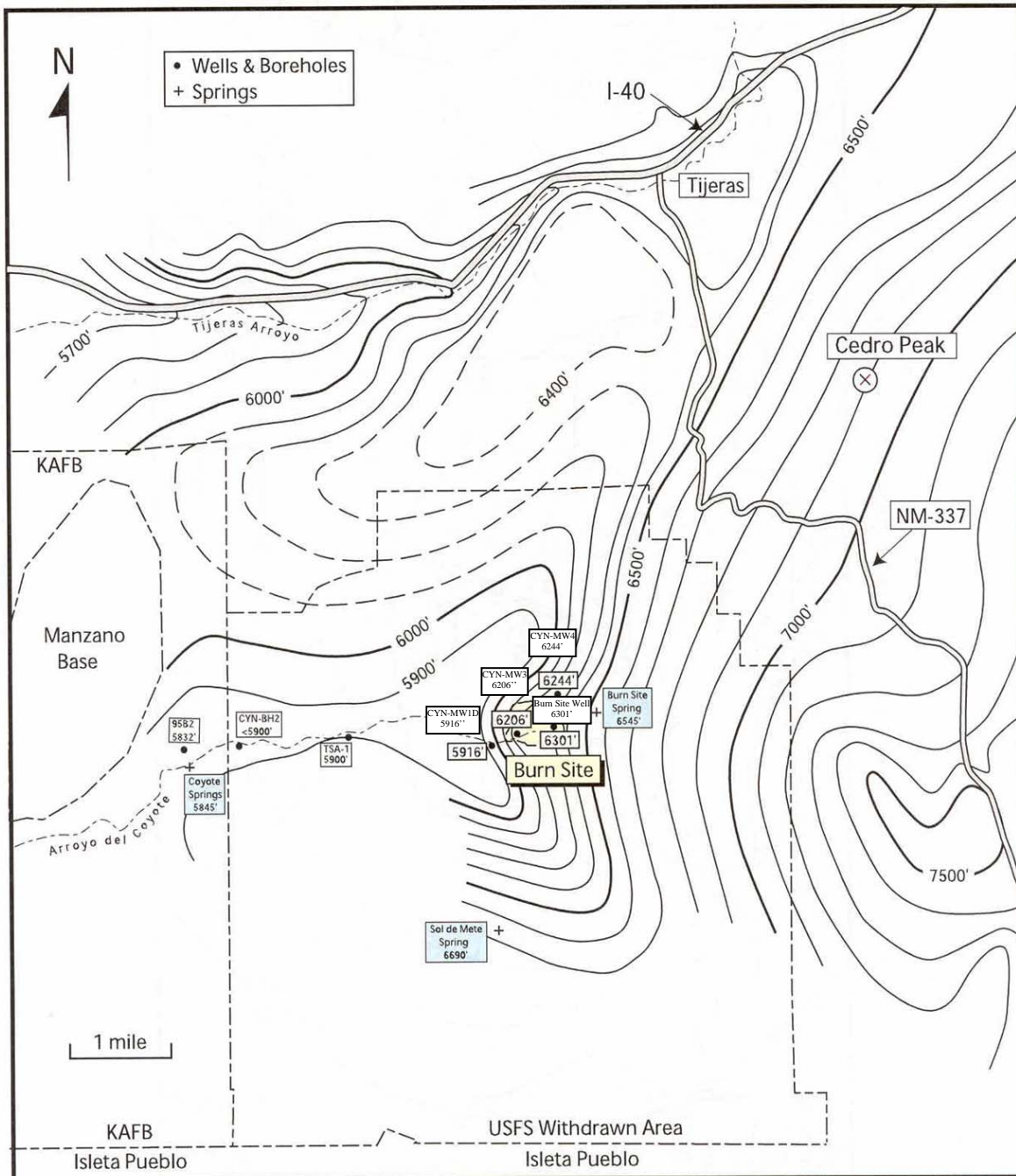
#### 2.1.1 Regional Setting

The Manzanita Mountains include a complex sequence of uplifted Precambrian metamorphic and granitic rocks that were subjected to significant deformation throughout geologic history. These rocks are capped by Paleozoic shales and limestones of the Sandia Formation and Madera Formation.

Groundwater in the western Manzanita Mountains occurs primarily in fractured Precambrian metamorphic and intrusive rocks and in the Pennsylvanian sedimentary rocks. Precambrian rocks include metavolcanics, quartzite, metasediments, and the Manzanita Granite. Pennsylvanian sedimentary rocks consist of the Sandia and Madera Formations. Groundwater in these rocks moves primarily as flow through fractures. The permeability of these fractured rocks characteristically is low and well yields are small.

The fractured rocks of the Manzanita Mountains are recharged by infiltration of precipitation, largely occurring in summer thundershowers and, to a lesser degree, from limited winter snowfall on the higher elevations. Recharge is restricted by high evapotranspiration rates (i.e., losses to the atmosphere by evaporation and plant transpiration) and low permeability of the fractured bedrock.

Groundwater in the western Manzanita Mountains moves generally to the west (Figure 2-1) from a groundwater flow divide located east of the Burn Site (SNL/NM 2001a). East of the divide, groundwater moves toward the Estancia Basin located east of the Manzanita Mountains. West of the divide, groundwater moves beneath the Burn Site and enters the unconsolidated basin-fill deposits of the Albuquerque Basin as underflow.



From SNL/NM 2001a, with northern and eastern parts adapted from Titus (1980).

Figure 2-1. Groundwater potentiometric surface elevation contours for the Burn Site and surrounding area.

Based on field observations, some discharge occurs at springs along the mountain front. Much of the flow that discharges from these springs is likely lost to the atmosphere through evapotranspiration. Some flow from the springs probably infiltrates alluvial deposits.

The regional groundwater potentiometric surface elevation map (Figure 2-1) indicates that the generally westward flow direction is modified locally by topographic features. Deeply-incised canyons may provide local points of discharge through fault zones where the potentiometric surface intersects the canyon floor.

## **2.1.2 Burn Site**

This section presents hydrogeologic characteristics specific to the Burn Site (Section 2.1.2.1) and a summary of the site conceptual model of nitrate distribution and transport at the Burn Site (Section 2.1.2.2). Section 2.1.2.2 provides the basis for determining the initial nitrate concentrations simulated in the model, as discussed in Section 3.

### **2.1.2.1 Geology**

The Burn Site lies within Lurance Canyon, located in the Manzanita Mountains east of the Albuquerque Basin. The terrain is characterized by large topographic relief (exceeding 500 ft). Lurance Canyon, deeply incised into Paleozoic and Precambrian rocks, provides local westward drainage of surface flows to Arroyo del Coyote. Groundwater flow at the Burn Site is controlled by the local geologic framework and structural features.

The Precambrian metamorphic rocks typically are fractured as a result of the long and complex history of regional deformation. Core data and exposures indicate that fractures are filled with chemical precipitates in the upper portions of these rocks. These fracture fillings likely occurred when the water table was elevated prior to the development of the Rio Grande. As chemical precipitates filled fractures, permeability was effectively reduced, creating a semi-confining unit above the underlying fractured rocks.

The Burn Site is cut by a north-trending system of faults, consisting locally of several high-angle normal fault zones downfaulted to the east. Where exposed to the surface, these faults are characterized by zones of crushing and brecciation. The Burn Site fault extends north in the vicinity of the Burn Site well and well CYN-MW4. The estimated displacement of this fault may be as much as 160 ft based on exposed contacts.

Excavation of an unlined wastewater disposal pit at the Light Air Transport Accident Resistant Container (LAARC) unit revealed a zone of brecciated rock that may be a fault zone or a splay of the Burn Site fault. A sequence of north-trending normal faults has been mapped to the west of the Burn Site; these faults generally are downfaulted to the east. Other faults existing in the area are covered with alluvium.

### **2.1.2.2 Hydrology**

Water available for recharge of groundwater flow systems in the Manzanita Mountains is derived from precipitation. Recharge may occur when precipitation falls directly on surface exposures of brecciated fault zones. Recharge also may occur when stormwater runoff of snowmelt infiltrates canyon-floor sediments and moves across fault zones that subcrop beneath the sediments. Investigations have been conducted at two sites near the Burn Site to evaluate groundwater flow within canyon floor sediments.



Streamflow occurs episodically in the Arroyo del Coyote channel in response to precipitation in the drainage basin. A United States Geological Survey (USGS) stream-gauging station was operated during 1990-1995 on Arroyo del Coyote approximately 7 miles downstream from the Burn Site ([http://nwis.waterdata.usgs.gov/nm/nwis/discharge/?site\\_no=08330565](http://nwis.waterdata.usgs.gov/nm/nwis/discharge/?site_no=08330565)). This station monitored streamflow from a drainage area of about 35 mi<sup>2</sup>, including the 2.8 mi<sup>2</sup> drainage area above the Burn Site. A total discharge of 137 acre-ft of water occurred during July through September of 1991. A total discharge of 12 acre-ft of water occurred during May through September of 1994. With the exception of several other short episodes of surface water flow, no flow was measured during the remainder of the period of record. No discharge records are available for Arroyo del Coyote after 1995.

Based on the 6-year period of streamflow recorded for Arroyo del Coyote and on the distribution of rainfall at the meteorological station during 1995-2003 (SNL/NM 2004c), runoff at the Burn Site is sporadic and is associated with summer thundershowers. Periodic recharge to the alluvial sediments in Lurance Canyon is dependent on precipitation patterns in the 2.8 mi<sup>2</sup> drainage upstream from the Burn Site.

Infiltrating water from streamflow temporarily saturates alluvial sediments adjacent to the arroyo. Much of the water retained as bank and channel bottom storage likely returns to the atmosphere through evapotranspiration. If infiltrating water from a flow event or sequence of events is adequate to exceed evapotranspiration losses, water moves downward through the canyon alluvium and is available to enter brecciated fault zones and fractures in underlying bedrock.

Two piezometers were installed between 1996 and 1997 at the Burn Site to evaluate the potential for shallow groundwater flow in the channel alluvium at the interface with bedrock. No water was detected in the piezometers until September 2, 2004 when moisture was detected in one of the piezometers. After a series of significant rain events, between 1 and 2 inches of water was measured in the piezometer. The water level remained fairly constant through September. However, there has been no measurable water present in the piezometers since that time. It is possible that moisture is present in the vadose zone only after a series of significant rain events. Episodic accumulation of precipitation may provide a mechanism for recharge through brecciated fault zones and fractures in the underlying bedrock.

Groundwater in rocks underlying the Burn Site is semi-confined and moves primarily through fractures, eventually discharging to unconsolidated, basin-fill deposits in the Albuquerque Basin to the west. Some discharge takes place to springs at the base of the Manzanita Mountains.

#### **2.1.2.3 Nitrate in Groundwater near the Burn Site**

Nitrate is present in groundwater near the Burn Site at concentrations that exceed the MCL (10 mg/L as nitrogen). This nitrate may be derived either from nitrate residue following open detonation of HE or from the concentration of nitrate by evapotranspiration of rainfall that infiltrates the canyon alluvium. Nitrate from either source could accumulate in alluvial deposits in the canyon floor and be mobilized by subsequent wetting events that provide sufficient moisture to infiltrate fracture systems and brecciated fault zones, eventually migrating downward to the bedrock groundwater flow system.



As part of the CME, a recent investigation of nitrate concentrations in groundwater and alluvium was conducted. The following conclusions were derived from this evaluation:

- Nitrate in alluvium and groundwater at the Burn Site is a result of both natural phenomena and historical Burn Site operations.
- Elevated nitrate concentrations in soil near the Burn Site and in a groundwater plume emanating from the Burn Site could have resulted from historical Burn Site operations and subsequent leaching of nitrate into the subsurface.
- Nitrate remains in the vadose zone at the Burn Site; however, this nitrate does not represent an active source that would significantly increase future nitrate concentrations in groundwater. Nitrate remaining in the vadose zone is unlikely to result in groundwater contamination at concentrations higher than have been observed in the past (SNL/NM 2005b).

The spatial distribution of nitrate in groundwater supports the conceptual model that a series of complex local flow systems is controlled by the orientation, hydraulic conductivity, and interconnections of faults and fractures. Although the potentiometric surface elevation contours indicate that groundwater flows generally westward, the north-trending primary conductivity of the brecciated fault zones likely permits migration of groundwater through those zones. Groundwater movement to the west occurs through the low-permeability fracture network that poorly connects brecciated fault zones.

The historical and current distribution of nitrate in Burn Site groundwater is pertinent to the evaluation of transport and dilution. This distribution is characterized by observations of nitrate concentrations in several wells that are in the vicinity of the Burn Site, as shown in Figure 1-3. These observations include:

- The Burn Site well was drilled in 1986 but no nitrate data were collected until 1996. The measured nitrate concentration in 1996 was 25 mg/L (expressed as nitrogen).
- Since the completion of wells CYN-MW1D (December 1997) and CYN-MW3 (June 1999), nitrate concentrations exceeding the MCL have been consistently detected in these wells.
- Nitrate concentrations in water from the Burn Site well have decreased from 25 mg/L in 1996 to 5.5 mg/L in 2001. Concentrations in water from well CYN-MW3, approximately 1,400 ft downgradient from the Burn Site well, have ranged from 10 to 15 mg/L since 1999. Nitrate concentrations in water from well CYN-MW1D, located approximately 3,400 ft west of the Burn Site well, have increased from approximately 10 mg/L in 1998 to more than 25 mg/L. The concentration trends in the Burn Site well and well CYN-MW1D suggest that a pulse of nitrate-enriched groundwater has migrated past the Burn Site well and arrived in the vicinity of well CYN-MW1D, located 3,400 ft to the west. However, the relatively stable nitrate concentrations at CYN-MW3 do not reflect this pulse, which may be caused by complex, local-scale flow paths.

- Nitrate concentrations in water from well CYN-MW4, cross-gradient from the Burn Site, have not exceeded 0.65 mg/L.
- Well CYN-MW5 is located approximately 2 miles west (downgradient) of well CYN-MW1D. Nitrate concentrations in seven water samples collected from this well since July 2002 ranged from 2.07 to 2.55 mg/L. Coyote Springs is located approximately 3 miles west (downgradient) of well CYN-MW1D. Nitrate concentrations in six water samples collected from this spring between April 1997 and June 2004 ranged from 0.08 to 0.85 mg/L. Nitrate concentrations in well CYN-MW5 and Coyote Springs are interpreted to represent background.

## **2.2 *Albuquerque Basin***

The geologic and hydrologic conditions of the Albuquerque Basin control groundwater flow and contaminant migration to potential human receptors at production wells. This section briefly describes the regional hydrogeologic setting (as defined by large-scale geologic features), the hydrostratigraphic framework of the Albuquerque Basin and the basin-fill sedimentary units of the Santa Fe Group, regional recharge and discharge, and configuration of regional groundwater flow.

### **2.2.1 Large-Scale Geologic Features**

The Rio Grande Rift is a relatively continuous regional structural feature that extends north from Mexico, across New Mexico, and into southern Colorado. Formation of this feature began 25 million years ago in northern Mexico when tectonic forces began to pull apart the brittle upper crust of the North American Plate and continued toward the north.

The Rio Grande Rift is marked by a series of sediment-filled structural basins and adjoining uplifted mountain ranges. One of these basins, the Albuquerque Basin (also known as the Middle Rio Grande Basin), covers about 3,060 mi<sup>2</sup> in central New Mexico and extends from the Cochiti Reservoir on the north to San Acacia, New Mexico on the south. The Albuquerque Basin includes the city of Albuquerque (COA) and parts of Santa Fe, Sandoval, Bernalillo, Valencia, Socorro, Torrance, and Cibola Counties.

The major fault systems that bound the Albuquerque Basin have dominated the development of geologic and hydrologic features within the basin. These fault systems consist of sets of subparallel, high-angle, large-displacement normal faults that separate the subsided basin from adjoining uplifted mountain blocks. Fault blocks on the inside of the rift zone typically have dropped down relative to uplifted fault blocks on the eastern and western edges of the rift.

Rift zone faulting has controlled sedimentary deposition within the Albuquerque Basin throughout its history. Continued movement along faults has modified local drainage systems and formed topographically high areas that provided a ready source of newly-eroded sediments. Fault offsets brought Santa Fe Group sediments into contact with upfaulted Paleozoic rocks along the basin margins. Because active faulting was occurring at the same time as sedimentary deposition, faults also have offset stratigraphic units within the Santa Fe Group. In addition, fault zones have served as conduits for vertical groundwater flow and as regional hydrologic boundaries of the Santa Fe Group aquifer.

The uplifted mountains to the east of the Albuquerque Basin act as groundwater flow boundaries and provide a source of streamflow and alluvial sediments to the basin from mountain drainages. Streamflow originating from these drainages furnishes a source of surface-water recharge to alluvial fan sedimentary deposits along the basin margins. Chemical interactions between water and rocks in these drainages affect the chemistry of water recharged to the Santa Fe Group aquifer.

### **2.2.2 Hydrostratigraphic Framework**

The Albuquerque Basin is filled with sedimentary deposits of the Santa Fe Group. Basin-fill deposits of the Santa Fe Group within the Albuquerque Basin are composed of distinct lithofacies, defined by depositional mode and characterized largely by texture. The ancestral Rio Grande (ARG) lithofacies consists of well-sorted, coarse-grained, fluvial sands and gravels that were transported from distant sources to the north during the development of the through-flowing drainage of the Rio Grande. ARG sediments typically are highly permeable. The alluvial fan lithofacies consists of poorly sorted, lenticular sand, silt, and clay derived from more local drainages where uplifted rocks along the eastern edge of the Rio Grande Rift were eroded. These sediments typically are much less permeable than the coarser sediments of the Rio Grande.

### **2.2.3 Regional Recharge**

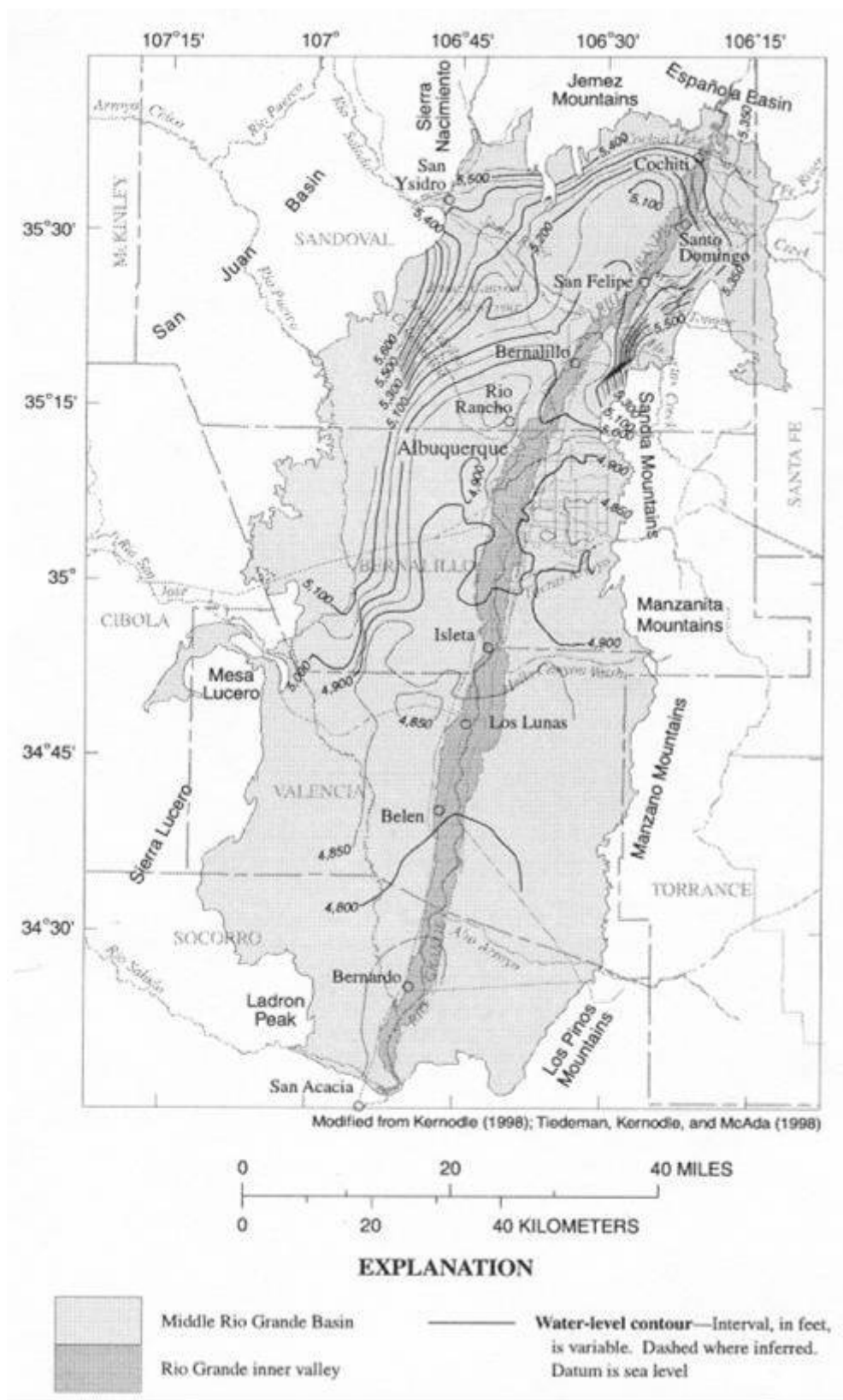
Recharge to the Santa Fe Group aquifer occurs from infiltration of streamflow from the Rio Grande and arroyos, from infiltration of areal precipitation, and from underflow originating from mountain-front recharge. On the federal property that includes SNL/NM, Tijeras Arroyo and Arroyo del Coyote provide limited recharge, as does mountain-front recharge, where it connects across the fault complexes. Infiltration of precipitation through the vadose zone is estimated to provide a negligible contribution to groundwater within the Albuquerque Basin, as 95 to 99% or more is estimated to be lost to evapotranspiration (SNL/NM 1998).

### **2.2.4 Regional Discharge**

Regional discharge occurs as groundwater moves out of the Albuquerque Basin into downgradient basins on the Rio Grande Rift as underflow or through discharge to the Rio Grande. Discharge also occurs from pumping at the COA municipal production well fields. The discharge is greater than recharge and effectively dewateres the aquifer on the federal property.

### **2.2.5 Regional Groundwater Flow**

Prior to development of water resources in the Albuquerque area, groundwater in the Albuquerque Basin flowed generally from the north to the south, with a westward component of flow from recharge areas along mountain-front boundaries to the east (Bartolino and Cole 2002). As the Santa Fe Group aquifer has been developed as a source for municipal and industrial water supplies, groundwater flow directions have been partially altered toward pumping centers (Figure 2-2).



From Bartolino and Cole 2002

Figure 2-2. Configuration of the regional groundwater surface in the Albuquerque Basin, 1994-1995.

On SNL/NM and KAFB property, the predominant groundwater flow was westward prior to water resources development (Bexfield and Anderholm 2000). Recent potentiometric surface elevation contour maps and numerical modeling studies show the significant hydrologic influence of the pumping centers just north of the federal boundaries. The Ridgecrest supply wells, in particular, are completed less than 1 mile north of the federal boundary and are screened in the north-south trending fluvial deposits. The capture zones of these wells extend south onto federal property (SNL/NM 2001b; Plate 3-2). The U.S. Air Force owns and operates a lesser influential network of supply wells within the federal boundaries. Together, these pumping centers contribute to the present post-development north-northwest groundwater flow direction in the ARG lithofacies.

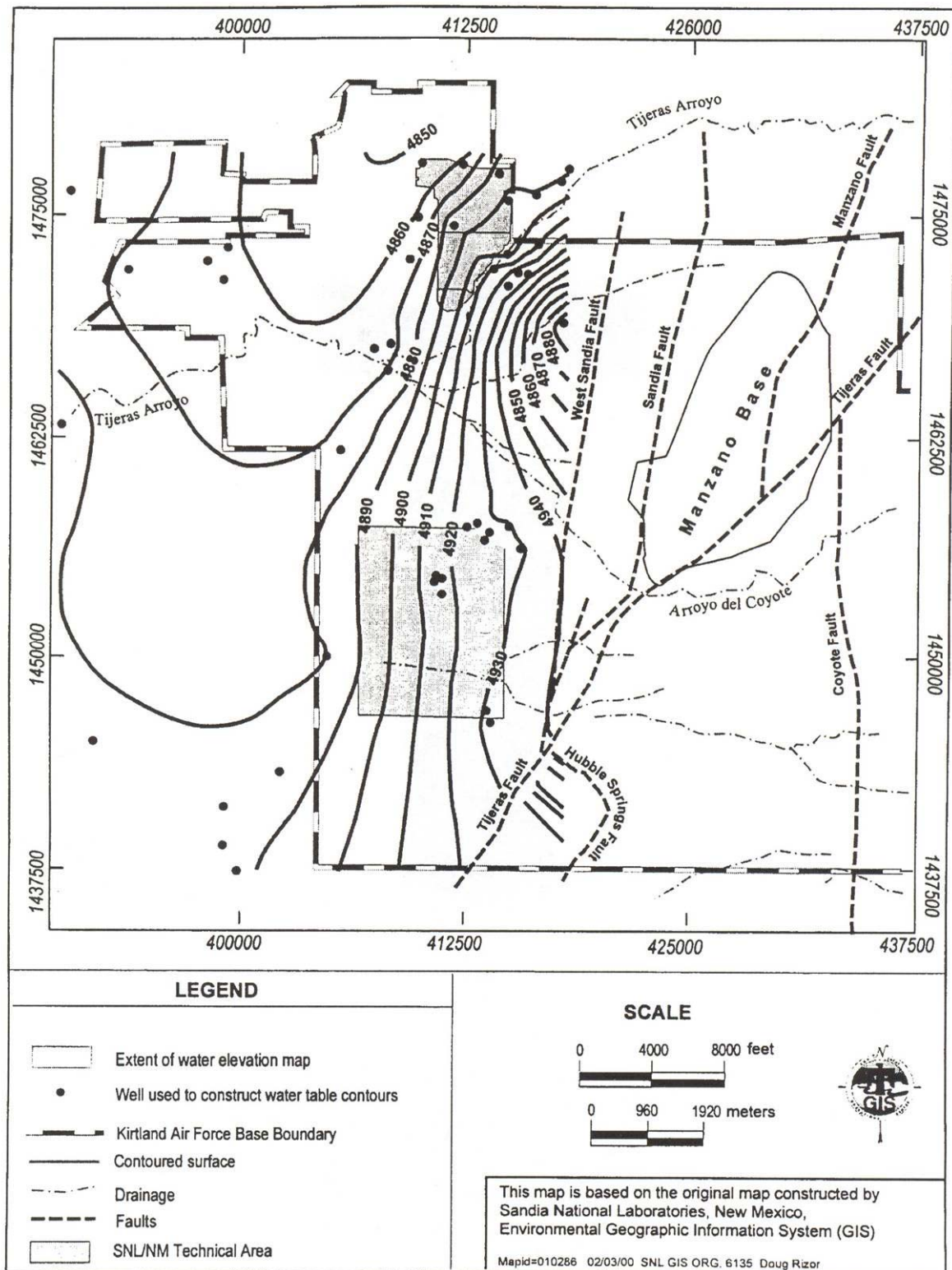
### **2.2.6 Hydrostratigraphic Units**

The aquifer in the alluvial fan lithofacies consists of fine-grained, clay-rich sediments of the alluvial fan lithofacies of the Santa Fe Group. These sediments interbed with the highly permeable sediments of the ARG to the west.

The horizontal hydraulic conductivity of the alluvial fan lithofacies ranges from about 0.1 to 35 ft/day, based on aquifer tests conducted in several wells completed in the alluvial fan lithofacies (SNL/NM 2004c). The horizontal hydraulic conductivity of the ARG is as high as 150 ft/day. The vertical hydraulic conductivity of both lithofacies is considered to be much lower because of the layered characteristics of the sediments. The effective porosity (a measure of the interconnected pore spaces in the alluvial fan lithofacies) is approximated from measurements of total porosity and moisture content to be 25%.

### **2.2.7 Groundwater Flow in Alluvial Fan Lithofacies**

Groundwater in the alluvial fan lithofacies is derived principally from mountain-front recharge to the east. Groundwater flows generally from east to west (Figure 2-3) through the low-permeability alluvial fan lithofacies, as shown on the subregional 2000 potentiometric surface map (SNL/NM 2000). The measured hydraulic gradient through these deposits is approximately 0.005, based on water-level differences between wells. Potentiometric contours indicate that groundwater flowpaths intercept the high-permeability ARG lithofacies and turn to the north in response to pumping at the large municipal well fields north of KAFB. Based on a reasonable range of hydraulic properties, the velocity of groundwater flowing through the alluvial fan lithofacies is estimated to range from 0.5 to 168 ft/yr.



GW00-5-1.ai

From SNL/NM 2000

Figure 2-3. Subregional potentiometric surface elevation contour map for basin fill deposits west of Lurance Canyon, 2000.

### 3.0 MODELING APPROACH

A numerical modeling study was performed to evaluate the effect of dilution by recharge and underflow on nitrate concentrations during transport from the Burn Site area to potential downgradient receptors. Potential downgradient receptor locations include:

- Springs downgradient of the Burn Site, and
- Pumping centers in the ARG lithofacies, including Ridgecrest well field and other potential pumping centers.

Figures 3-1 and 3-2 illustrate the groundwater flow path from the current location of contaminants near the Burn Site to these potential receptor locations. This flow path was interpolated based on potentiometric data and hydrogeologic properties described in Section 2.0. For the evaluation of nitrate transport, this flow path was divided into four sections that represent changes in flow regime from the fractured metamorphic and sedimentary rocks to the basin-fill deposits of the Albuquerque Basin. These sections include:

1. Lurance Canyon Model Section. This section included various bedrock aquifers poorly connected by faults and fracture systems in which groundwater flows generally westward. A 10.6-mile long cross-sectional numerical model was devised to simulate flow in this region. The model section was simulated as a confined system based on observations of confined conditions.
2. Transition Section. Based on geologic evidence, this is a complex region intersected by fault zones (Figure 3-2). Flow through this 1.6-mile region was not simulated in a numerical model because the data needed to parameterize a model are not available. In lieu of explicitly simulating flow and transport in this segment of the flow system, a conservative assumption was made. Groundwater discharging from the downgradient end of the Lurance Canyon model section was assumed to be transported conservatively and instantaneously to the upgradient end of the alluvial fan model section without attenuation of nitrate. This approach was conservative in that it did not account for the dispersion and dilution that would actually occur during transport through this segment of the flow system.
3. Alluvial Fan Model Section. This region included westward groundwater flow in alluvial fan lithofacies at the eastern edge of the Albuquerque Basin. Groundwater in this section was derived primarily from mountain front recharge from the east. A 2.6-mile long simplified cross-sectional model was devised for this section in which flow from the Lurance Canyon section comprises a portion (0.8%) of the total flow through the alluvial fan section.
4. ARG Model Section. Groundwater flows northward through this region toward COA pumping centers. This region was simulated using a 10-mile long simplified cross-sectional approach in which flow from the alluvial fan section formed a portion (1%) of the total flow through the ARG section.



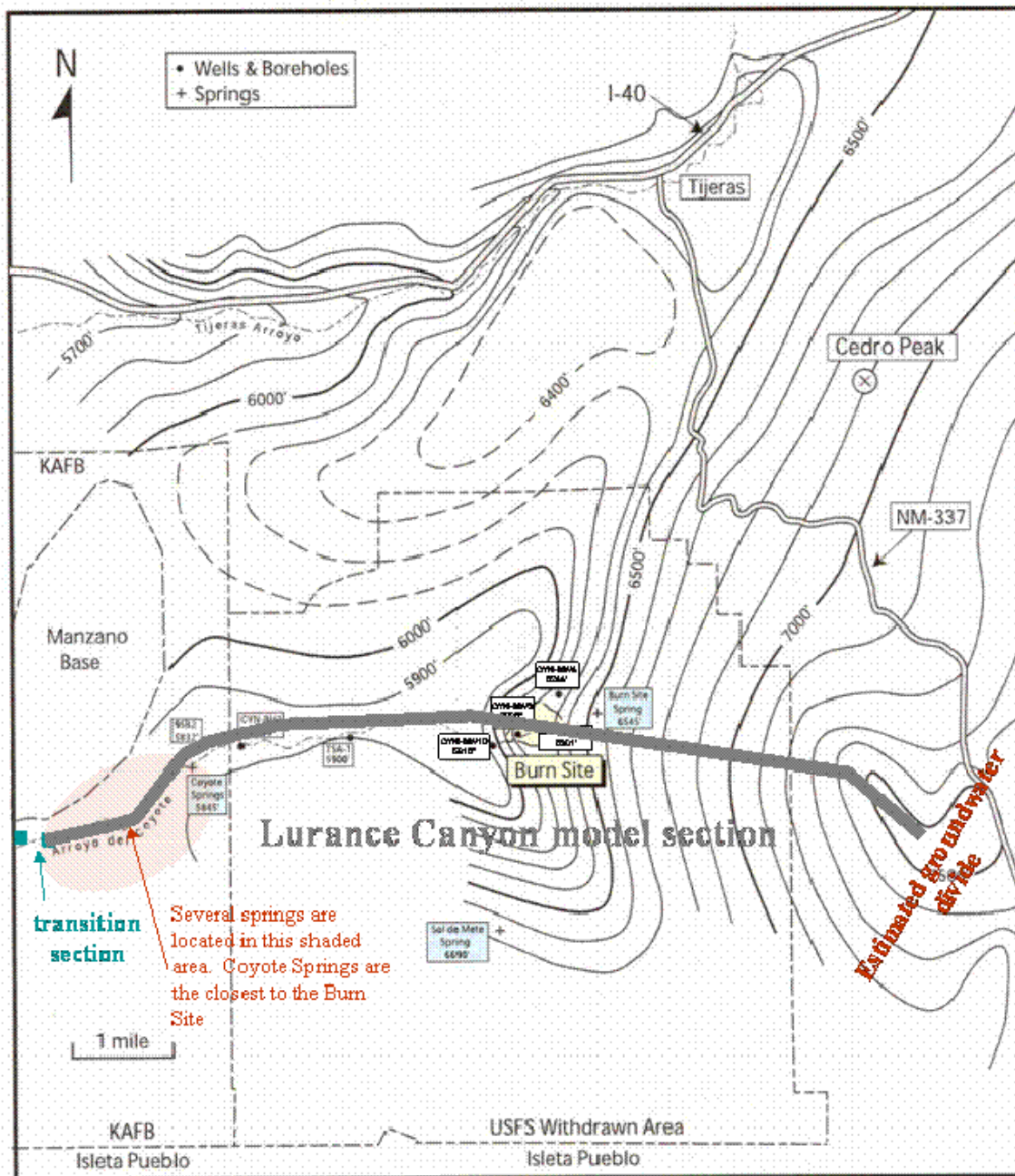
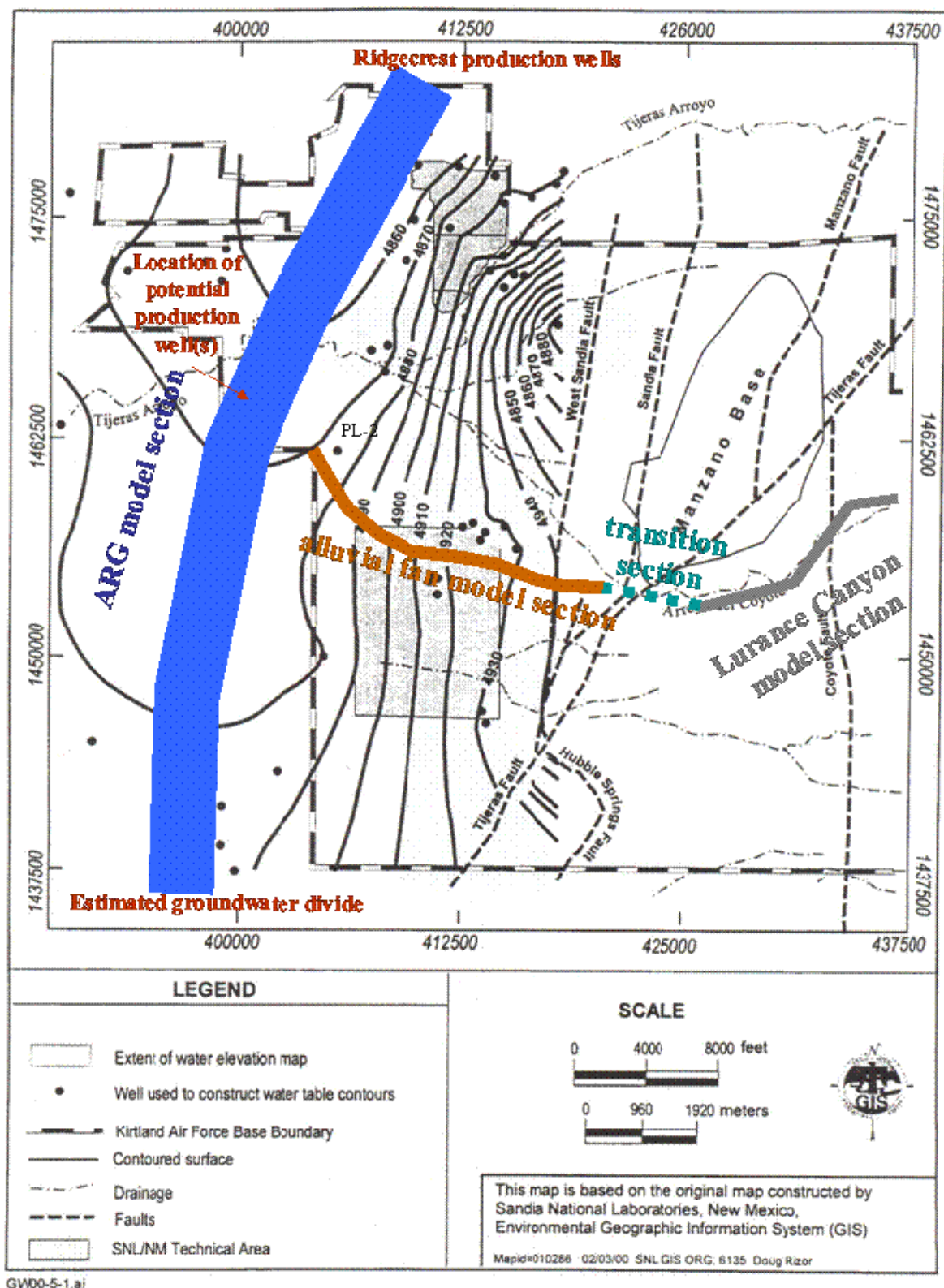


Figure 3-1. Location of the Lurance Canyon model section.





The simulated initial nitrate concentration was representative of the observed nitrate distribution in Burn Site groundwater. The initial maximum concentration was 1 unit, which represents the highest observed concentrations near CYN-MW1D. Attenuated downgradient nitrate concentrations were expressed as a fraction of this initial concentration.

The cross-sectional modeling study was performed using the Department of Defense Groundwater Modeling System (GMS), employing the MODFLOW groundwater model (Harbaugh et al. 2000) and the MT3DMS transport model (Zheng and Wang 1999) with GMS pre- and post-processors (BYU 2003). Table 3-1 provides summary information and input parameters for each of the four sections. Sections 3.1 through Section 3.4 of this report provide detailed information and input parameters about each model section.

Table 3-1. Summary information and input parameters for each of the four sections.

	<b>Lurance Canyon Model Section</b>	<b>Transition Section</b>	<b>Alluvial Fan Model Section</b>	<b>ARG Model Section</b>
Detailed description in	Section 3.1	Section 3.2	Section 3.3	Section 3.4
Flow model length	10.6 miles	1.6 miles	2.6 miles	10.0 miles
Nitrate transport distance within the model section	5.1 miles <sup>a</sup>	1.6 miles	2.6 miles	3.6 miles <sup>b</sup>
Width	1,000 ft	N/A <sup>c</sup>	1,000 ft	6,000 ft
Thickness	20 - 200 ft <sup>d</sup>	N/A <sup>c</sup>	200 ft	600 ft
Number of cells	56	N/A <sup>c</sup>	68	88
Upgradient boundary type	no flow, simulating groundwater flow divide	N/A <sup>c</sup>	constant head	no flow, simulating groundwater flow divide
Downgradient boundary type	constant head	N/A <sup>c</sup>	constant head	constant head
Hydraulic conductivity	0.01 ft/day	N/A <sup>c</sup>	8 ft/day	150 ft/day
Effective porosity	0.10%	N/A <sup>c</sup>	25%	25%
Potential receptor locations	Springs located downgradient of the Burn Site the closest of which are Coyote Springs.	None	None	Ridgecrest municipal pumping wells and other potential pumping wells in the ARG.

a. The Burn Site is located approximately 5.1 miles upgradient from the flow model downgradient boundary.

b. Nitrate laden underflow from the alluvial fan model section enters the ARG model section 3.6 miles upgradient of the Ridgecrest well field.

c. The transition section was not simulated in a numerical model.

d. All cells where nitrate transport is simulated are 200 ft thick.

### **3.1 Lurance Canyon Model Section**

The Lurance Canyon model section was a simplified representation of the groundwater flow system in various precambrian paleozoic formations that are poorly connected by faults and fracture systems. The approach provided a simplified simulation of groundwater flow and solute transport from the estimated groundwater divide located east of the Burn Site to the area southeast of Manzano Base (Figure 3-1) where multiple springs discharge at the surface. Coyote Springs are the closest downgradient springs to the Burn Site. In addition, the Lurance Canyon section model provided groundwater flux and contaminant concentration output that was used as a conservative estimate of the attenuated solute plume that may move through the transitional region and thence into the alluvial fan deposits.

The model was a two-dimensional, vertical cross-section, steady-state flow model. The section was simulated as a porous medium with homogeneous aquifer properties. This approach was intended to create a regional scale simulation of a system that is highly heterogeneous at more localized scales. The modeling approach smoothed localized variations in head and simulated the general head trend. As a consequence, the model is useful for evaluating the effects of dilution over a regional scale (i.e., miles) but is not appropriate for interpreting changes in concentration at a more local scale (i.e., less than 1,000 ft).

**Grid** – The model grid consisted of a single layer composed of 56 cells, each 1,000 ft long and 1,000 ft wide. This 10.6-mile length is the estimated distance along the expected flow path from the estimated groundwater divide to the area southeast of Manzano Base where groundwater discharges to several springs (Figure 3-1). The model cross-gradient width (1,000 ft) was selected to include both the flowpaths that emanate from the Burn Site and those that converge in Lurance Canyon downgradient of the Burn Site (Figure 3-1). The altitude of the upper surface of this model varied from 7,910 to 5,620 ft and was based on topographic contours and the potentiometric surface. The single-layer model was 20 ft thick east and upgradient of the Burn Site and 200 ft thick west and downgradient of the Burn Site. The thickness and hydraulic conductivity dimensions were chosen to provide a simplified representation of the accumulation of flow paths.

**Boundaries**—The simplified numerical model represented a groundwater flow that originated at a groundwater divide located approximately 4.5 miles east and upgradient of the Burn Site. The section was approximately 10.6 miles long and followed a flow path through the Burn Site area and down Lurance Canyon to a constant head boundary located near the springs at the mouth of the canyon (Figure 3-1). These springs include “G” Spring, Cattail Spring, and Homestead Spring. The potentiometric elevation of the constant head boundary was interpolated from the elevation of these springs and water-level elevation measurements in the well Greystone-MW2 (SNL/NM 2004d).

**Hydrologic Properties** –Homogeneous hydraulic properties were assumed for the saturated rocks throughout the Lurance Canyon section. Values for hydraulic conductivity, porosity, and other parameters were single values throughout the cross-section and did not take into account localized characteristics at fault zones and other geologic features. The input values were as follows:

- A horizontal hydraulic conductivity of  $10^{-2}$  ft/day was uniformly assigned to model cells. This value represents the magnitude of the bulk value as derived from estimates of gradient, effective porosity, and velocity (SNL/NM 2004c).
- Effective porosity of  $10^{-3}$  was uniformly assigned to model cells. This value is within the expected range for fractured rock, as derived from literature values (SNL/NM 2004c).
- By nature of the cross-sectional single-layer model, anisotropy and vertical flow were neglected.
- The system was assumed to be confined. This assumption was based on observations of confined conditions during well construction and on observations of cemented fractures in rocks above the water-bearing units (see Section 2).

**Initial Nitrate Concentrations**—Throughout the simulation, concentrations were represented as a fraction of the initial nitrate concentration. The simulated initial nitrate distribution was an approximation of the current distribution of nitrate in Burn Site groundwater but was not intended to be an exact representation. This simulated solute plume had a maximum concentration of 1 unit; therefore, maximum concentrations at various locations and times during the simulation were represented as a fraction or percentage of this initial maximum. The maximum concentration (1 unit) was applied uniformly throughout the cell, which represents a location near CYN-MW1D. The current nitrate plume was simulated by applying concentrations of 0.5 and 0.25 in the two cells downgradient of the maximum concentration cell and the two cells upgradient of the maximum concentration cell (Figure 3-3).

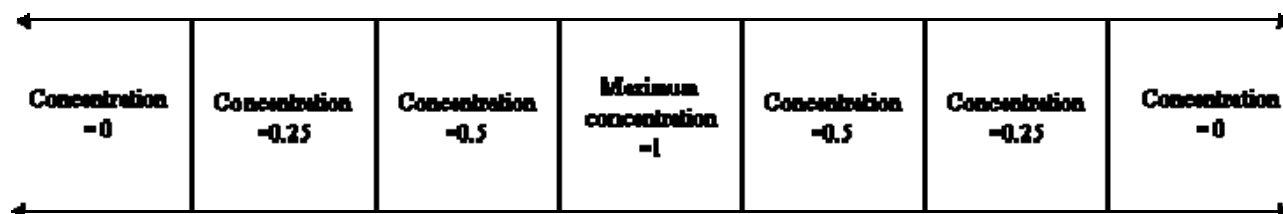


Figure 3-3. Illustration of assigned initial nitrate concentrations in cells near well CYN-MW1D.

**Model Calibration**—Recharge to the groundwater flow system at the Burn Site is derived from infiltration of precipitation. Recharge was simulated by injection of water at imaginary wells in each cell. Simulated heads were calibrated to observed heads by varying the recharge rate, as simulated by injection into the imaginary wells. In keeping with the regional scale approach, recharge values were averaged over regions of similar conditions. For example, a region representing the bottom of Lurance Canyon included elevated recharge rates to account for episodic streamflow and an observed accumulation of groundwater flow paths.

The elevation of the groundwater divide to the east and the elevation of the water surface in three wells and five springs in the Burn Site area provided calibration points to produce a reasonable approximation of head distribution along the 10.6-mile model length. The elevation of the groundwater divide was interpolated from a regional water-table map. Recent water-level measurements in the three wells (SNL/NM 2004d) and the land-surface elevation of springs were used in the model calibration.

Figure 3-4 presents the simulated head distribution along the cross-section and includes observed head at several locations for comparison. Figure 3-5 presents a plot of simulated heads as compared to observed heads. As shown on these two plots, the model provided a reasonable simplified representation of regional distribution of water levels. A more precise match between simulated and observed heads would have required a detailed characterization of the bedrock medium and local hydrogeologic features and additional measurements of groundwater levels along the flow path. However, the purpose for this simplified numerical model was not to produce an exact distribution of head but to permit a reasonable, simplified representation of groundwater flow and contaminant transport.

Simulated recharge into individual cells varied between 0.02 and 1.7 ft<sup>3</sup>/day. Smaller recharge values were specified for the steep mountain slopes and the larger recharge values were specified to simulate recharge on the canyon floor from accreted mountain-slope runoff and episodic stream flow. When this flow is divided by the surface area of each cell (10<sup>5</sup> ft<sup>2</sup>), the range of recharge corresponds to 0.0007% to 0.06% of the daily precipitation, as estimated at various elevations (SNL/NM 2004b). Two reasons for this apparently small percentage are (1) Averaging the recharge over the entire area may lead to small recharge values in individual cells, considering that most of the recharge to this aquifer likely occurs through localized fault zones and fracture systems, and (2) The fraction of precipitation that recharges groundwater is expected to be small given the arid climate and evapotranspiration losses.

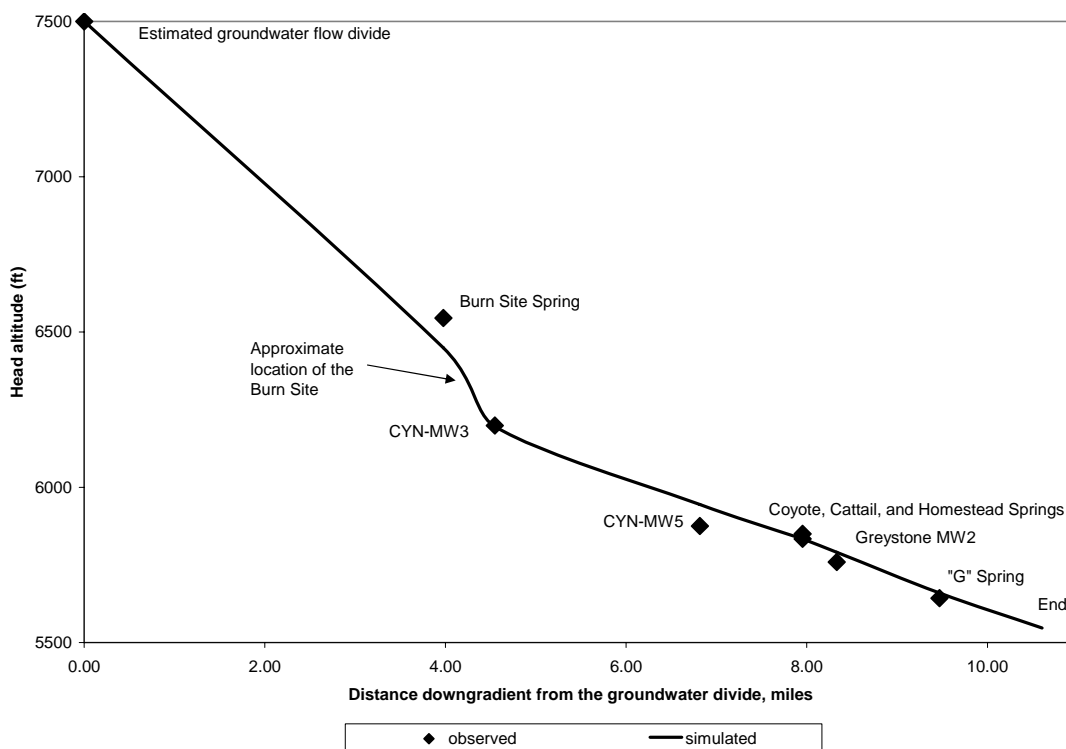


Figure 3-4. Comparison of simulated and observed potentiometric head along the Lurance Canyon model section.

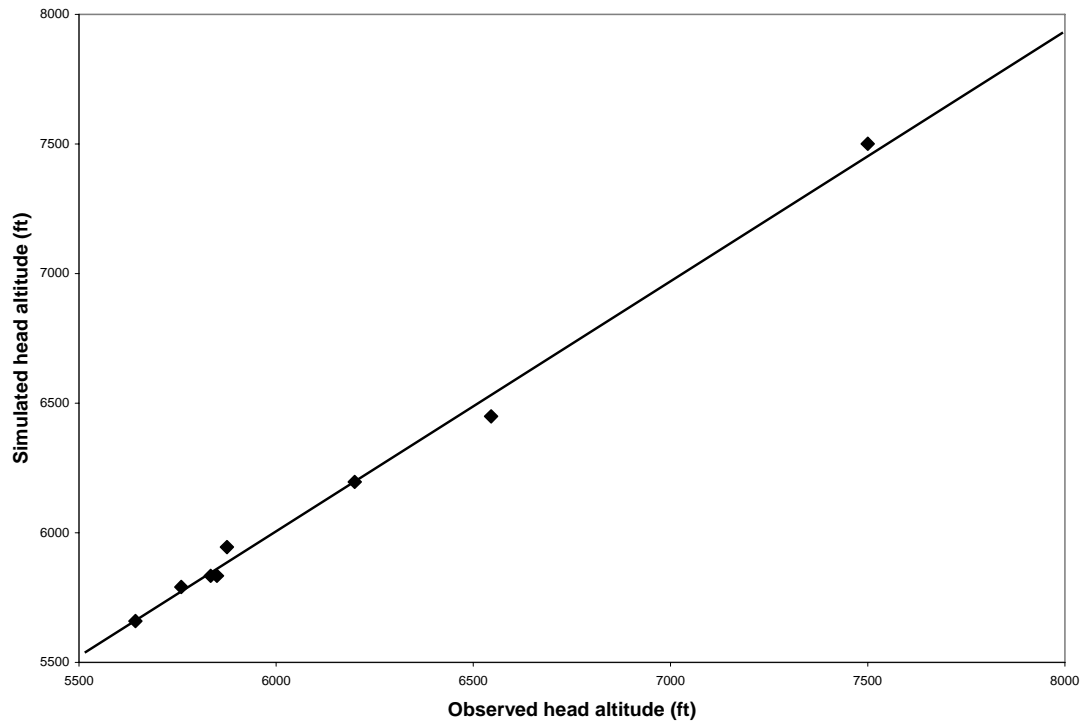


Figure 3-5. Comparison of simulated and observed heads along the Lurance Canyon model section.

### 3.2 Transitional Section

Groundwater flow in the area between the downgradient constant head boundary of the Lurance Canyon section and the interface where underflow enters the alluvial fan lithofacies of the Albuquerque Basin is complex and uncharacterized. Therefore, for simplicity, it was assumed that groundwater flow out of the downgradient constant head boundary of the Lurance Canyon section provided a portion of the flow into the alluvial fan section; when in fact, the end of the Lurance Canyon section and the beginning of the alluvial fan section are spatially separated by over 1 mile (Figure 3-2). This approach was conservative because potential dispersion or dilution effects on solutes during transport across this region were ignored, and transport time through this region was neglected. Another conservative assumption was that solute mass was not lost as groundwater in the Lurance Canyon section drained to the springs and that all of the solute was transferred directly into the alluvial fan section.

### 3.3 Alluvial Fan Model Section

The alluvial-fan cross-sectional model represented the groundwater flow system that extends west through the low-permeability alluvial fan lithofacies of the Albuquerque Basin from the mountain front to the high-permeability ARG lithofacies, as observed on the local potentiometric surface map (Figure 3-2). Flow through the alluvial fan lithofacies is horizontally preferential because of the layered, lenticular nature of these deposits. Water along this flowpath generally originates from mountain-front recharge to the east, a portion of which may include underflow originating from bedrock flow systems, including those in the vicinity of Lurance Canyon.

**Grid**—The simplified numerical model represented a groundwater flowpath that extended 2.6 miles west and northwest from the mountain front and Arroyo del Coyote to a location south of well PL-2 in the ARG deposits (Figure 3-2). The model section consisted of a single layer, with the top at an altitude of 4,960 ft and the bottom at an altitude of 4,760 ft. The model section also consisted of a single row with 68 cell columns from east to west, with cell dimensions 200 ft long and 1,000 ft wide. The width dimension and total depth were the same as the dimensions used in the Lurance Canyon section.

**Boundaries and Hydrologic Properties**—The model represented mountain-front recharge with a constant head boundary at an altitude of 4,940 ft, as derived from the regional potentiometric surface (Figure 3-2). The downgradient terminus of the flowpath was represented by a constant head boundary that was defined by the altitude of an observed water level of 4,872 ft in well PL-2.

The flow out of the Lurance Canyon section contributed to the flow into the alluvial fan section. This contribution was simulated in the alluvial fan section using an injection well near the eastern (i.e., mountain front) end of the section. A steady-state injection rate equal to the total flow out of the Lurance Canyon section (45 ft<sup>3</sup>/day) was maintained in this well. Because the flow system was simulated using constant heads at both ends, this addition of water did not affect the flow budget but provided a means of simulating contaminant addition into the alluvial fan section from the Lurance Canyon section.

No flow was assumed to move across the longitudinal dimensions of the cross-section because the section was considered to be parallel to the flow path derived from the potentiometric surface. No flow was assumed to occur beneath the layer. Although this assumption is not true, it is considered to be conservative in this context because a thicker aquifer would result in increased dilution of a contaminant.

A USGS regional flow model used an east-west range of hydraulic conductivity from 0.1 ft/day near the mountain front to 150 ft/day in areas of the ARG, with a value of 8 ft/day in cells simulating alluvial fan deposits (Bexfield and McAda 2003). This hydraulic conductivity (8 ft/day) was used uniformly in the alluvial fan section. An effective porosity of 0.25 (derived from the same regional model) was applied uniformly in this model segment.

**Calibration**—The simplified numerical model was calibrated by comparing simulated head to observed water level in five wells along the section. Simulated heads in cells representing four wells ranged from 1 ft higher to 2 ft lower than observed heads. The cross-sectional flow model permitted a reasonable representation of flow and transport. The average gradient over the entire cross-section was constrained by the constant head boundaries at each end, which were based on the regional potentiometric surface map and observed water levels (Figure 3-2).

**Flow Model Results**—Simulated flow through the cross-sectional model moved from east to west. An average flux of 5,928 ft<sup>3</sup>/day moved out of the model at the downgradient constant-head boundary during the simulation, representing flow out of a 1,000-ft wide strip of the upper section of alluvial fan deposits into the ARG. This representation is considered to be reasonable, given known distribution of head and hydraulic conductivity.

**MT3DMS Transport Assumptions**—Numerical results from the cross-sectional flow model were used to evaluate the downgradient transport and dilution of a solute in groundwater. The following assumptions were made:

- The solute is not sorbed by the aquifer solid phase and therefore is transported without retardation in groundwater,
- The solute does not degrade,
- Dispersion is neglected, and
- Porosity was assumed to be 0.25. This is a reasonable and accepted value for porous media and was used in the USGS regional model (Bexfield and McAda 2003).

The groundwater and solute flux out of the Lurance Canyon section was applied directly into the eastern end of the alluvial-fan section using an imaginary injection well. Flow out of the Lurance Canyon section was assumed to contribute a portion of the flow into the alluvial-fan section and contaminants were assumed to be conservatively and instantaneously transported through the transitional region. As shown in Figure 3-6, the solute flux out of the Lurance Canyon section into the alluvial fan section was simulated by stepping concentrations up and then down throughout the time period of major solute flux across the boundary, which was approximately 200 years divided into 40 stress periods. Flux of water containing the contaminant was equal to the flow out of the Lurance Canyon section ( $45.26 \text{ ft}^3/\text{day}$ ).

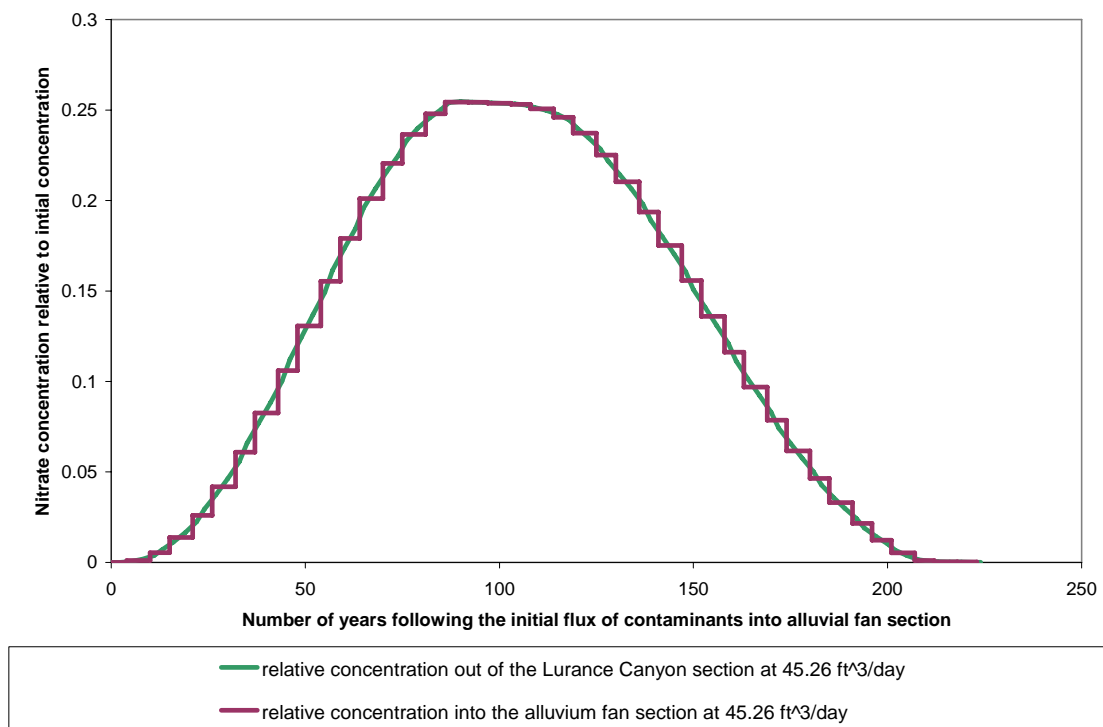


Figure 3-6. Illustration of flux simulation from Lurance Canyon model section into the alluvial fan model section.



### 3.4 *Ancestral Rio Grande Model Section*

The ARG model section began south and west of KAFB near an estimated groundwater divide separating flow toward pumping centers to the north from natural system flow to the south. The section represented flow northward through the high-permeability ARG lithofacies, as inferred from water-table contour maps (Figure 3-2). Water along this flowpath generally accretes from underflow out of alluvial fan deposits to the east and recharge from the Rio Grande to the west. Flow through the ARG lithofacies is preferential horizontally because of the layered, lenticular nature of these deposits. Little, if any, recharge from rainfall occurs along the flowpath.

**Grid**—The ARG model section represented a groundwater flowpath that extended 10 miles north from the estimated groundwater flow divide to the Ridgecrest well field. The model section consisted of one layer, with the bottom at an altitude of 4,400 ft. This bottom elevation included most of the aquifer thickness presently utilized by pumping wells but did not account for flow within underlying Santa Fe Group sediments.

The model section consisted of 88 cells, with cell dimensions 600 ft long (direction of groundwater flow) and 6,000 ft wide (cross-gradient). The width dimension was used to represent most of the flow through the ARG that would be derived from accreted flows from the east.

**Boundaries and Hydrologic Properties**—The estimated groundwater divide to the south was simulated as a no-flow boundary. The cumulative cone of depression in the water table in the vicinity of the Ridgecrest well field has steadily developed over time (because of continuous pumpage) to meet municipal requirements. In the cross-sectional model, this cone of depression was represented at the northern terminus of the flowpath by a constant head at an altitude of 4,850 ft, which was the approximate water level in well Ridgecrest 4 in 2000. Accreted underflow originating from mountain fronts east of the ARG was represented by injection wells in each cell along the section.

A previous regional flow model used a hydraulic conductivity of 150 ft/day to represent the ARG (Bexfield and McAda 2003). This hydraulic conductivity was used uniformly in the steady-state ARG model section. Horizontal to vertical anisotropy was not represented in the one-layer model. An effective porosity of 0.25 was assigned to model cells based on the regional numerical model.

**Calibration**—The model was calibrated to observed water levels by adjusting injection-well contributions representing accreted underflow in each cell. Simulated heads were compared to observed water levels in four wells along the section. The cross-sectional flow model was not calibrated further because the intent was not to exactly reproduce distribution of head but to permit a reasonable, simplified representation of flow and transport to the Ridgecrest well field receptor. The calibrated injection rate representing underflow was 7,000 ft<sup>3</sup>/day into each cell.

**Flow Model Results**—Simulated flow through the ARG model section moved from south to north. A flux of 609,000 ft<sup>3</sup>/day moved out of the model at the downgradient constant-head boundary, representing flow out of a 6,000-ft wide strip of the ARG deposits into the area of influence of the Ridgecrest well field. For comparison, the annual withdrawal for all COA municipal wells for 2000 was estimated to be 110,000 acre-ft, or 13.1 million ft<sup>3</sup>/day. The simplified model of ARG groundwater flow represented less than 5% of total COA withdrawals.

This representation was considered to be reasonable, given the known distribution of head, hydraulic conductivity values, and water-withdrawal data.

**MT3DMS Transport Assumptions**—Numerical results from the cross-sectional flow model were used to evaluate the downgradient dilution of a solute in groundwater injected into cell 56, which is the estimated endpoint of a flowpath from alluvium. Transport assumptions for the numerical model were the same as those used for the alluvial fan section (Section 3.3).

Nitrate entered the ARG model section, with underflow from the alluvial fan lithofacies to the east, at a concentration that represented solute flux from the alluvial fan section. The method of input was similar to that used at the interface between the Lurance Canyon and alluvial fan section. The simulated flux out of the alluvial fan section and the simulated flux into the ARG section are demonstrated in Figure 3-7.

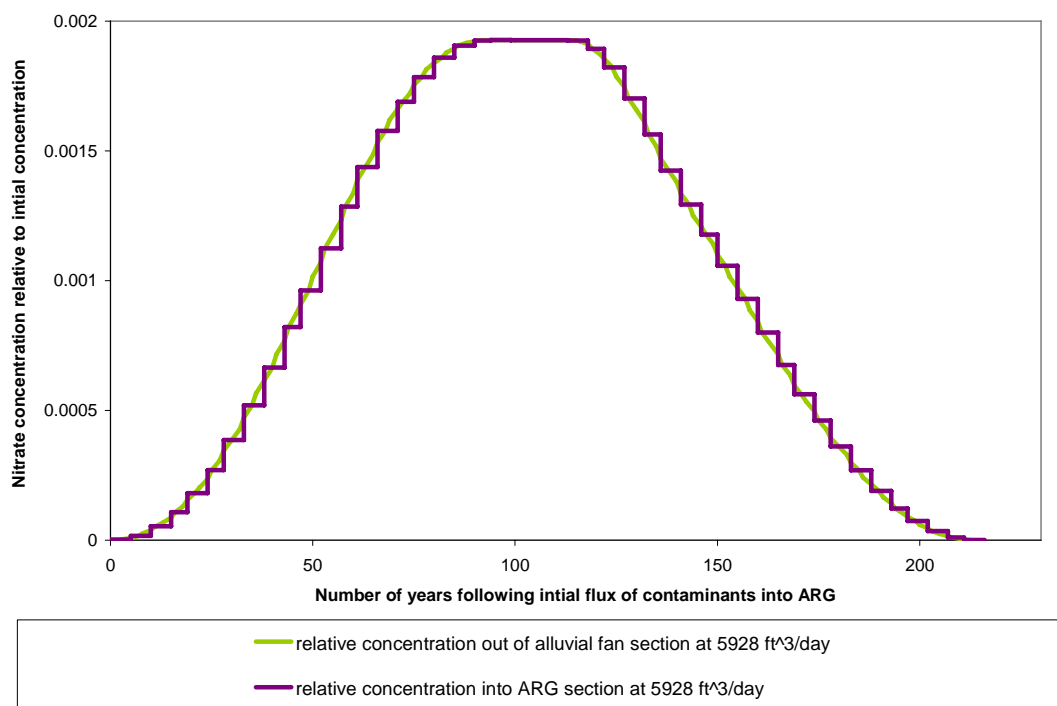


Figure 3-7. Illustration of flux simulation from the alluvial fan model section into the ARG model section.

Nitrate-bearing underflow was simulated by injection in cell 56 (56 cells or 6.4 miles downgradient from the estimated groundwater divide) at a concentration representing the flux of contaminant from the alluvial fan section. The cell dimensions between the alluvial fan and the ARG sections were not the same; therefore, flow out of the alluvial fan section represented a portion (85%) of the total underflow into cell 56. Accordingly, two imaginary injection wells were assigned to cell 56. The first injected water at a flow equal to the total flow out of the alluvium (5,928 ft<sup>3</sup>/day) and nitrate concentrations, as shown in Figure 3-6. The second well injected water without solute at a flow of 1,072 ft<sup>3</sup>/day to simulate the total 7,000 ft<sup>3</sup>/day of underflow into the cell.

Nitrate injected into cell 56 was assumed to mix completely with ambient water in the cell. This mixing was more likely to occur between the location represented by cell 56 and the groundwater withdrawal at pumping centers. The assumption was not considered to be conservative with respect to downgradient concentrations but provided a qualitative assessment of the overall effect of dilution in the ARG prior to reaching potential receptors where groundwater is withdrawn.

## 4.0 RESULTS

The modeling approach outlined in Section 3.0 incorporated the conceptual model summarized in Section 2.0 into a simplified and conservative numerical model for evaluating reduction in simulated nitrate concentration. Simulated nitrate in groundwater is transported to potential ecological receptors at downgradient springs and human receptors at production wells in the ARG. This section presents results of transport modeling using the Lurance Canyon, transition, alluvial fan, and ARG model sections. This section is divided into a discussion of the transport results through the Lurance Canyon model section to springs (Section 4.1) and transport results to production wells (Section 4.2).

### 4.1 *Transport to Coyote Springs*

Nitrate transport to Coyote Springs was simulated using the Lurance Canyon model section. Nitrate concentrations were reduced from the initial maximum concentration of 1 unit (100%) as the solute plume migrated downgradient. This concentration reduction was a result of dilution caused by recharge and did not account for dispersion or potentially dramatic localized changes in permeability at fault zones.

The distribution of nitrate along the Lurance Canyon model section at initial conditions (time zero), 290 years, and 431 years is shown on Figure 4-1. Figure 4-2 shows the arrival times of the maximum nitrate concentration at Coyote Springs and the downgradient boundary of the Lurance Canyon model section. Figure 4-3 shows the maximum simulated nitrate concentration along the Lurance Canyon model section.

The closest receptor location to the Burn Site is Coyote Springs, which is approximately 2.8 miles downgradient from the current location of contaminants near the Burn Site. Breakthrough of the solute plume at Coyote Springs occurred after approximately 200 years (Figure 4-2); the maximum concentration of 0.28 concentration units (28% of initial concentration near the Burn Site) occurred after 290 years. Although there was no simulated drain at Coyote Springs, a conservative estimate of relative risk to a potential receptor at this location might assume that flow to this and other local springs is derived primarily from the simulated flow path. Therefore, water issuing from the springs would have a concentration trend as simulated.

The observed maximum nitrate concentration in Burn Site groundwater is 28 mg/L (SNL/NM 2005c). Therefore, a conservative interpretation of the modeling results suggests that the maximum observed concentration of nitrate at Coyote Springs will be 28% of 28 mg/L, or 7.8 mg/L observed after 290 years. Given the conservative assumptions built into this numerical model, the actual observed concentration at Coyote Springs may be less than 7.8 mg/L and may not be significantly above the NMED-approved background concentration of 4 mg/L (NMED 1997).

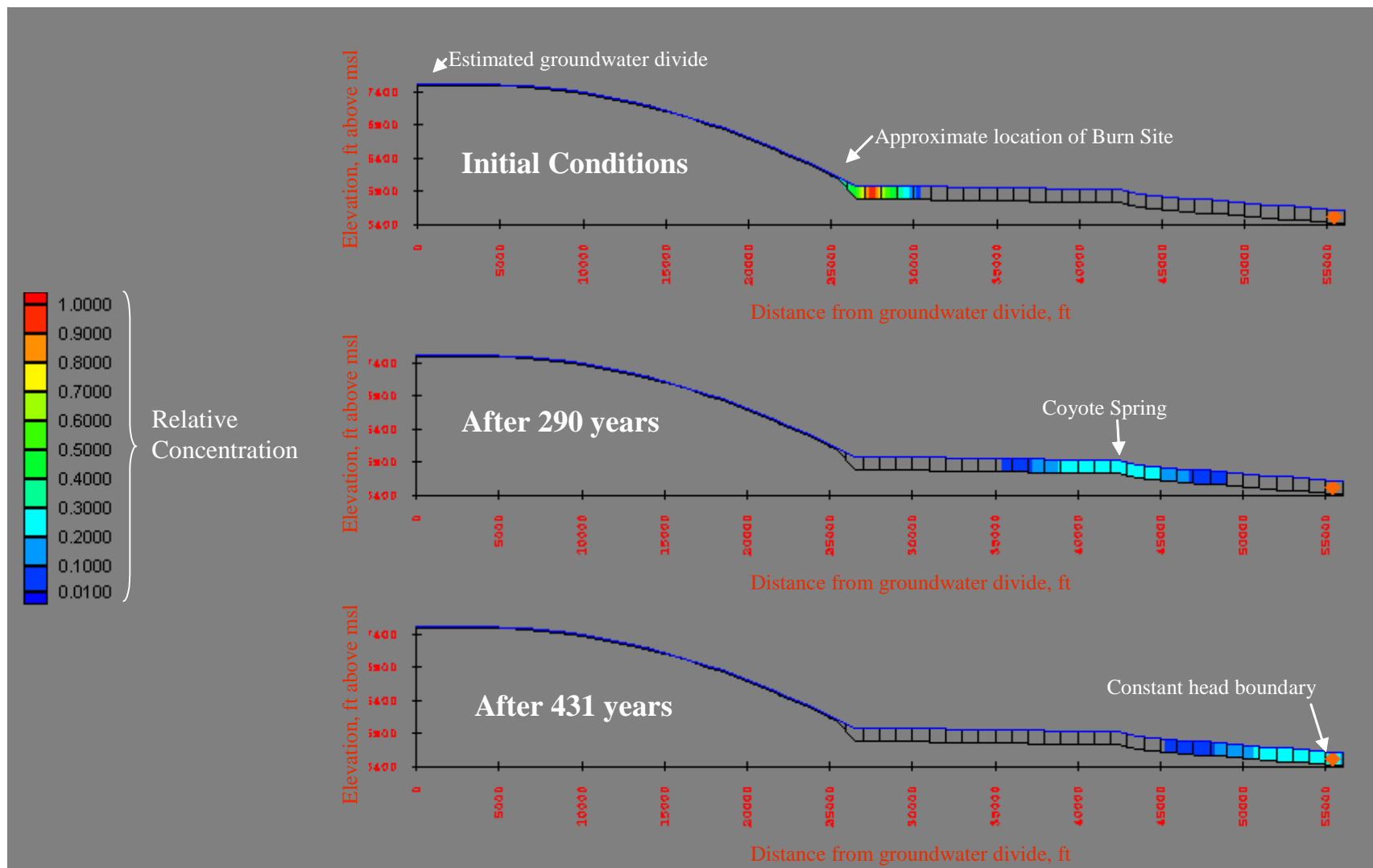


Figure 4-1. Nitrate transport in the Lurance Canyon model section (elevation axis is magnified 4X).

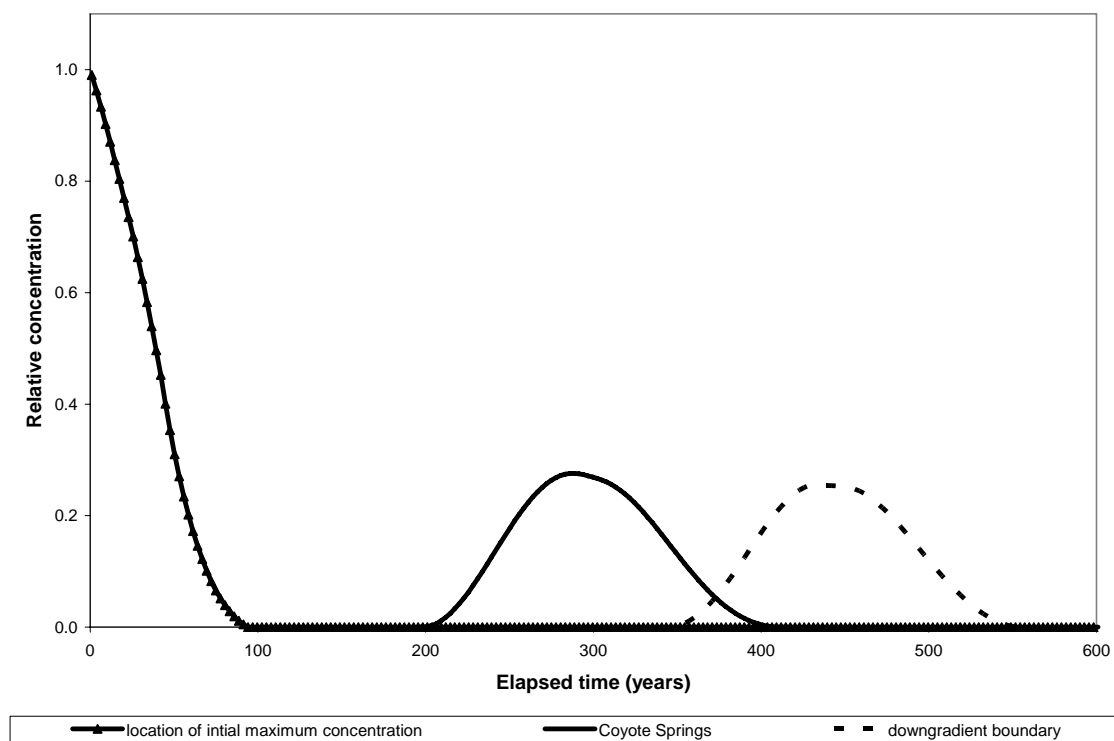


Figure 4-2. Nitrate breakthrough curves at the location of the initial maximum concentration, Coyote Springs, and the model downgradient boundary.

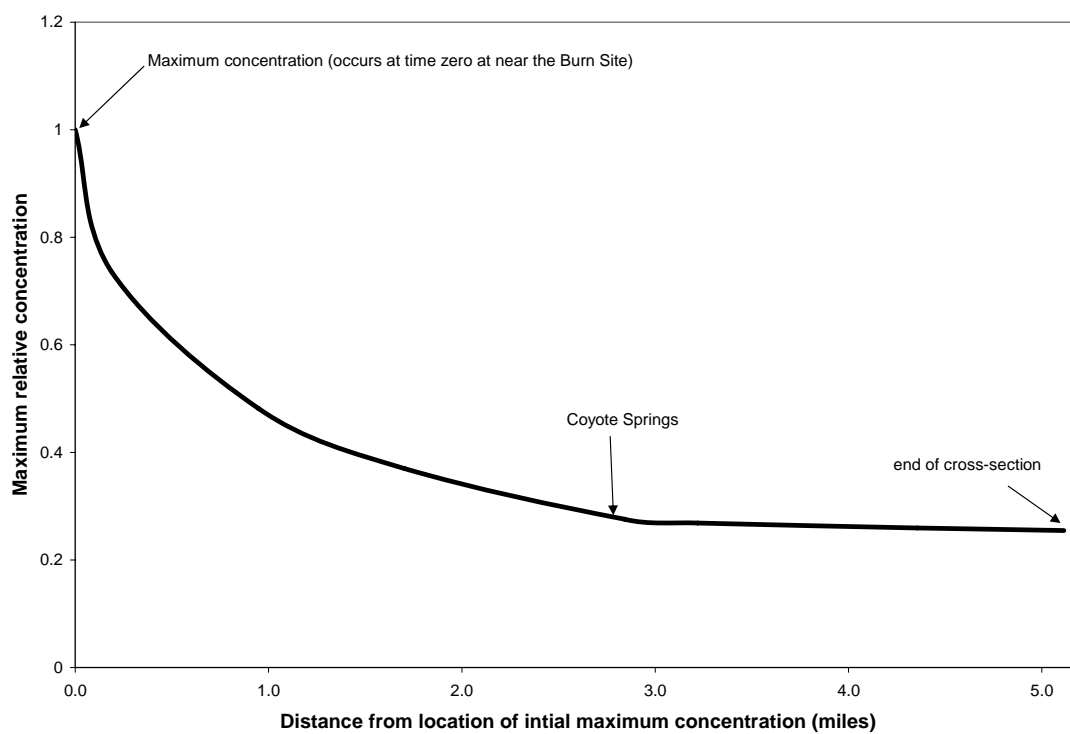


Figure 4-3. Maximum relative concentration with distance along the Lurance Canyon model section.

## 4.2 *Transport to Production Wells*

Nitrate transport from the Burn Site to the production wells was simulated using the Lurance Canyon, transition, alluvial fan, and ARG model sections. Figure 4-4 shows the maximum simulated concentrations at various locations along the flow path from the Burn Site to the Ridgecrest pumping wells and other potential production wells located in the ARG.

Observations from this simulation include:

- The downgradient boundary of the Lurance Canyon section was simulated to be 5.1 miles downgradient from the current location of contaminants. Initial breakthrough at this point occurred after 340 years of transport; a maximum concentration of 0.25 units (25% of the initial maximum) moved through the cell after 430 years.
- An assumption of the evaluation approach was that the solute is transported conservatively and instantaneously through the complex transitional region and is transported into the alluvial fan with underflow. This assumption is conservative with respect to concentration (e.g., observed concentrations may be less than simulated) and travel time (e.g., the simulated travel time through subsequent sections will be shorter than would be observed).
- As nitrate moved into the alluvial fan section, it was diluted to 0.002 concentration units (0.2% of the initial). This dilution was an effect of the small contribution of flow from the Lurance Canyon bedrock to the total flow through the alluvial fan, which was approximately 0.8% of the total flow.
- This attenuated plume was transported conservatively through the alluvial fan model section, where it moved into the ARG model section as underflow and was diluted further to  $3 \times 10^{-5}$  concentration units (0.003% of the initial).

Two pumping centers located within the ARG are considered potential human receptor locations for this nitrate. These include the Ridgecrest well field and a proposed pumping center located west of KAFB. The simulated maximum concentration at the Ridgecrest well field was 0.002%, and the initial maximum concentration in Burn Site groundwater at the location where nitrate enters the ARG model section was 0.003%.

The observed maximum nitrate concentration in Burn Site groundwater is 28 mg/L (SNL/NM 2005c). Therefore, a conservative interpretation of the modeling results suggests that the maximum observed concentration of nitrate at any human receptor location will be 0.003% of 28 mg/L or 0.0008 mg/L observed after at least 670 years (or 740 years to reach the Ridgecrest well field). Given that recent measurements of nitrate in the COA drinking water supply ranged from non-detect to 1.7 mg/L (City of Albuquerque 2003), and that the NMED-approved background level for nitrate is 4 mg/L, any additional nitrate from the Burn Site would be insignificant.

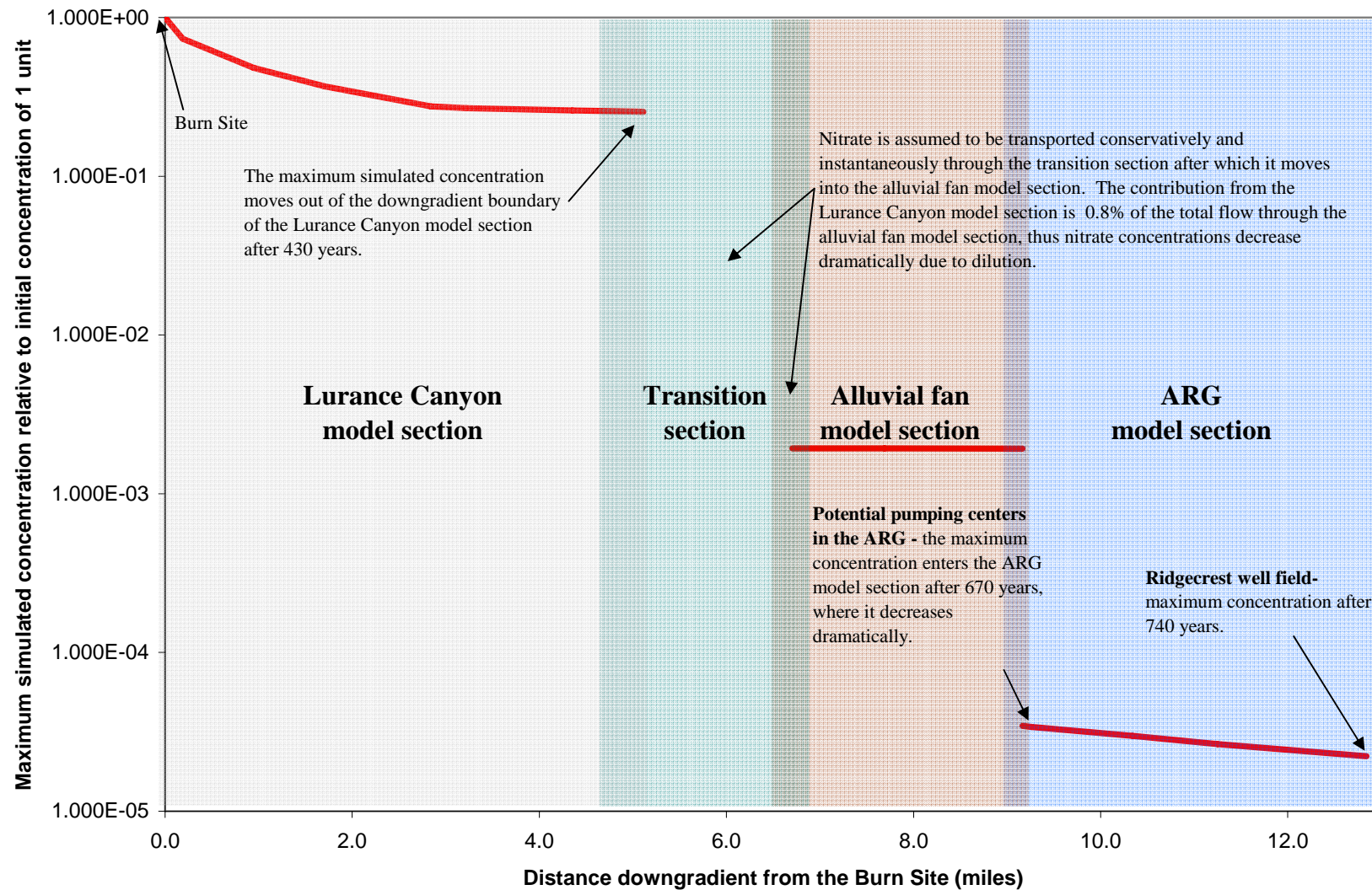


Figure 4-4. Plot of relative maximum concentration between current location and pumping centers.



## 5.0 SUMMARY AND CONCLUSIONS

A simplified cross-sectional modeling approach was used to simulate transport and dilution of nitrate between the current location of nitrate in Burn Site groundwater and potential human and ecological receptors. Four sequential sections were defined: (1) Lurance Canyon model section, (2) transition section, (3) alluvial fan model section, and (4) ARG model section. Simplified two-dimensional steady-state groundwater flow models were devised based on a previously developed conceptual model. Averaged hydrogeologic properties were chosen as input parameters to model flow in regions including east to west groundwater movement in bedrock, east to west groundwater movement in the Albuquerque Basin through alluvial fan lithofacies, and groundwater flow from south to north through the ARG lithofacies. Model sections were calibrated to observed hydraulic heads.

The cross-sectional flow models were used to conservatively simulate transport of nitrate from the current location of contaminants in Burn Site groundwater to potential downgradient receptor locations at springs and pumping centers. The resulting transport models were based on the following conservative assumptions:

- Dilution was the only attenuation process simulated. No attempt was made to account for dispersion, vertical transport, or biodegradation, which would further decrease concentrations.
- The simplified modeling approach neglected potential dilution at local brecciated fault zones where dramatic changes in hydraulic conductivity and porosity may occur over short distances.
- The simulation assumed conservative and instantaneous transport through the transition section, neglecting potential dilution as contaminants are transported across this region.

The simulation of nitrate transport resulted in the following conclusions regarding nitrate transport from the Burn Site to downgradient receptors:

- Simulated contaminant concentrations were diluted to 28% of the original concentrations before reaching Coyote Springs after 290 years. A conservative interpretation of the modeling results is that the maximum observed concentration at Coyote Springs will be 28% of 28 mg/L (maximum observed in Burn Site groundwater), or 7.8 mg/L. Given the conservative assumptions built into this numerical model, the actual observed concentration at Coyote Springs may be less than 7.8 mg/L and may not be significantly above the NMED-approved background concentration of 4 mg/L (see footnote 1).
- A conservative estimate of the nearest potential municipal pumping well is at the interface between the alluvial fan model section and the ARG model section. The simulated maximum concentration at this location is 0.003% of the maximum concentration at the Burn Site and occurs after 670 years. Continued transport through the ARG model section further decreased concentrations to 0.002% before reaching the Ridgecrest well field. A conservative interpretation of the modeling results suggests that the maximum observed concentration of nitrate at any human receptor location will be 0.003% of 28 mg/L or 0.0008 mg/L. Additional nitrate from the Burn Site would be insignificant and several orders of magnitude below the MCL of 10 mg/L.

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